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# ELEKTOR

64 ADDRESSES

# ELECTRONICS

THE INTERNATIONAL  
ELECTRONICS MAGAZINE

October 1994  
£ 2.45

TRANSFORMERS

## IN-CAR AUDIO AMPLIFIER

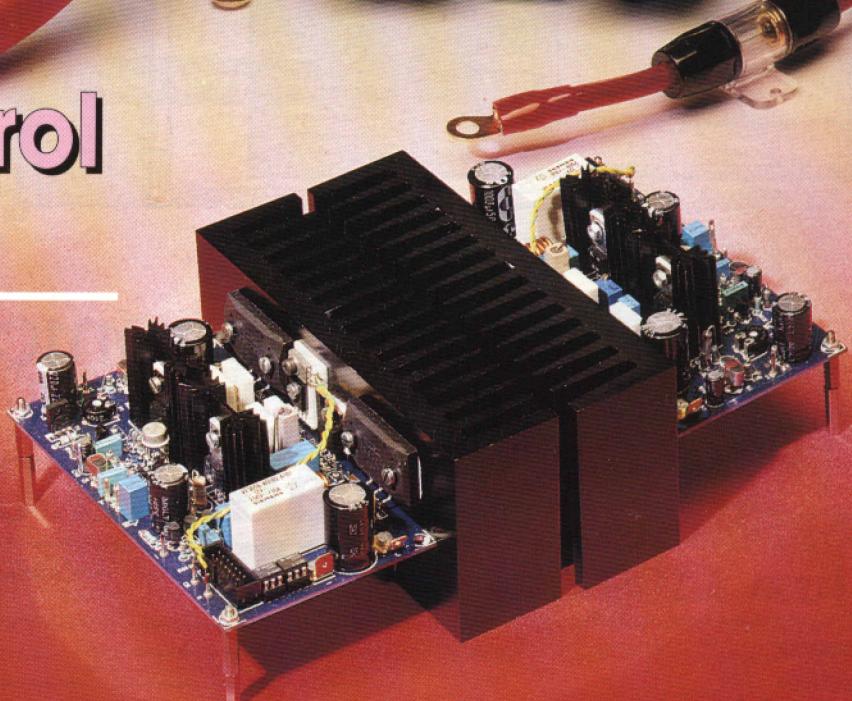
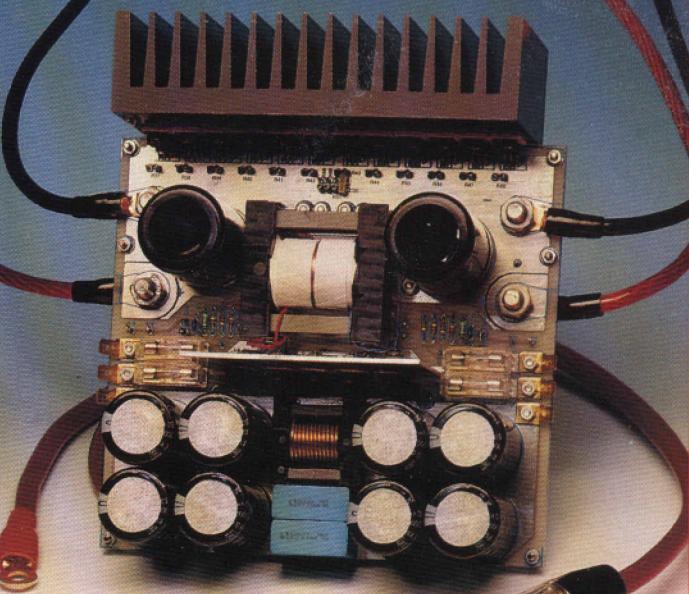
TV line monitor

Stable DC-DC  
converter

Computer PSU  
monitor

Infra-red  
remote-control  
tester

Voice  
scrambler



AUDIO & HI-FI • COMPUTERS & MICROPROCESSORS • DESIGN IDEAS • RADIO, TELEVISION & COMMUNICATIONS • SCIENCE & TECHNOLOGY • TEST & MEASUREMENT

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October 1994  
Volume 20  
Number 226  
ISSN 0268/4519

## Apologies

We regret that, owing to circumstances beyond our control, Part 20 of 'Figuring it Out' (Using a computer) has had to be postponed till next month.

## In next month's issue

- Single-wire communication
- Debugging the 8031 series
- Phantom power supply (for guitars)
- Centronics buffer for ISPLSI
- Simple capacitance meter
- Application note: Optical window comparator
- and others for your continued interest.

## Front cover

It appears that the in-car audio system has overtaken spot/fog lights, spoilers and sport steering wheels as the car status symbol of the mid-1990s. In line with that trend, here's our version of a 200 W in-car audio amplifier. But to those who are inclined to turn up the volume too high a warning: do not, as many before you, ruin your hearing; it's not worth it!

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**A B C**  
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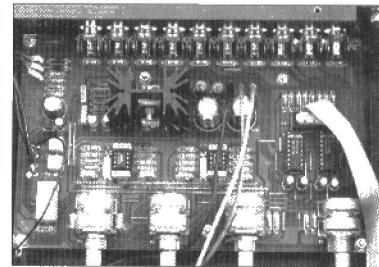
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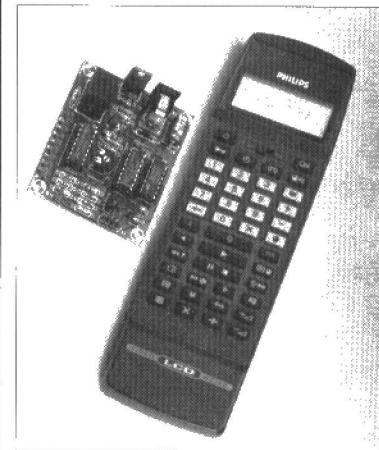
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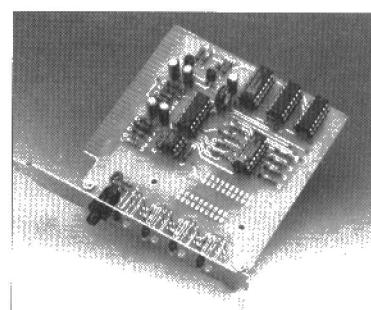
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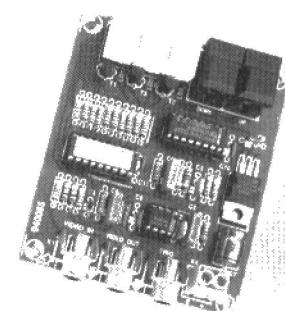
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## Mini I/O card for Casio FX850/880P

Since the legal arguments between the owner of the software copyright and the author of the article have been resolved, the floppy disk containing the program is now available again.

See page 31

# MOTIVE-BATTERY CHARGER

Design by L. Lemmens

**The battery charger is intended primarily for charging, and keeping charged, without supervision, lead-acid batteries of cars and motorcycles that are laid up for lengthy periods, for instance, during the winter.**

If a vehicle is laid up for a lengthy period, it is advisable to keep its (lead-acid) battery charged properly during this period as this will extend its life considerably compared to leaving it just in the vehicle and charging it when the vehicle is needed again. Unfortunately, the bulk of vehicle battery chargers is not suitable for unsupervised, continuous charging for long periods.

### Self discharge

Even when a lead-acid battery is not in use, its internal chemical action does not stop. Owing to small impurities in the acid, there are always tiny current loops in action, causing self discharge. In new batteries, this does not amount to much, just a few tenths of a per cent per day. Some self discharge also results from the electrochemical reaction between the lead dioxide of the positive plate lattices and the lead alloy of the grid. This is a form of corrosion, which in a fully charged battery is negligible, but can take on alarming dimensions in a neglected (discharged) battery. If the battery becomes totally discharged, the damage may be irreversible. This is because the lead sulphate formed in the plates during the discharge changes in structure: relatively large crystals of lead sulphate are formed which block the lattices in the plates. Both the negative and the positive plates become entirely sulphated and, as they are now composed of identical material, the terminal voltage collapses. The battery is then a write-off.

## Charging during layoffs

There is only one way of preventing a battery being destroyed through self-discharge and that is to keep it regularly charged. However, this should be done in an intelligent way, because overcharging a lead-acid battery is just as bad for it as a complete discharge. This means that a charger is required that does not just charge the battery, but also continuously monitors its condition and acts accordingly. Most commercial lead-acid battery chargers have no such facility and are thus totally

unsuitable for keeping a battery charged unsupervised.

## Charging current & voltage

The state of charge of a lead-acid battery is reflected by its cell voltage. Normally, this is 2 V. However, accurate measurements show that this voltage seldom has its nominal value. The cell voltage of a partly charged battery not in use is 1.9–2.0 V, that of a fully charged battery is 2.05–2.1 V. The charging voltage should be slightly higher, because during charging the cell voltage rises. In general, a battery is fully charged when its cell voltage has risen to 2.2–2.3 V (that is, 13.2–13.8 for a 12 V battery). When the cell voltage reaches 2.35–2.4 V, there is a sharp rise in voltage. Most of the charge is then used in dissociating the water of the sulphuric acid solution into hydrogen and oxygen and the cell begins to gas freely. It is thus advisable to treat 2.4 V as the upper limit of the cell voltage during charging.

There are three different ways of charging a battery: normal (the most common), fast and trickle.

The charging current during normal charging is one tenth to one twentieth of the nominal battery capacity in ampere-hours (Ah). Thus, a 20 Ah battery should be charged with a current of 1–2 A.

Fast charging takes place with a current that is three to five times larger than that used during normal charging. The condition of the battery needs constant monitoring, because the risk of overcharging is high. It is, in any case, advisable to use fast charging only in exceptional cases. Repeated fast charging reduces the useful life of the battery.

Trickle charging is not intended to charge a battery, but rather to keep it in good working condition by counteracting the effects of self discharge. The charging voltage should not be higher than 2.2 V per cell and the charging current may be limited to  $1/1000$  to  $1/2000$  of the battery capacity.

## Which charging method?

It is clear that for the present battery charger fast charging is not a method worth considering. Strictly speaking, trickle charging should do the trick. With proper design, a trickle charger could be left charging the battery for a whole year. Unfortunately, a trickle charger requires that from the onset the battery is fully charged. If the battery is partly discharged when it is laid up, a trickle charger would not be able to charge it in a year.

Therefore, the present charger uses a combination of normal charging and trickle charging. It is, in fact, a standard charger provided with voltage and current monitoring facilities. The charging current is 0.5 A; it can not rise above that level because of the internal protection circuits.

Since the charger also contains preset voltage limiting, the cell voltage of the battery on charge can not exceed a certain level. When, for instance, the preset voltage of 2.2 V is exceeded, the charging current is interrupted. When

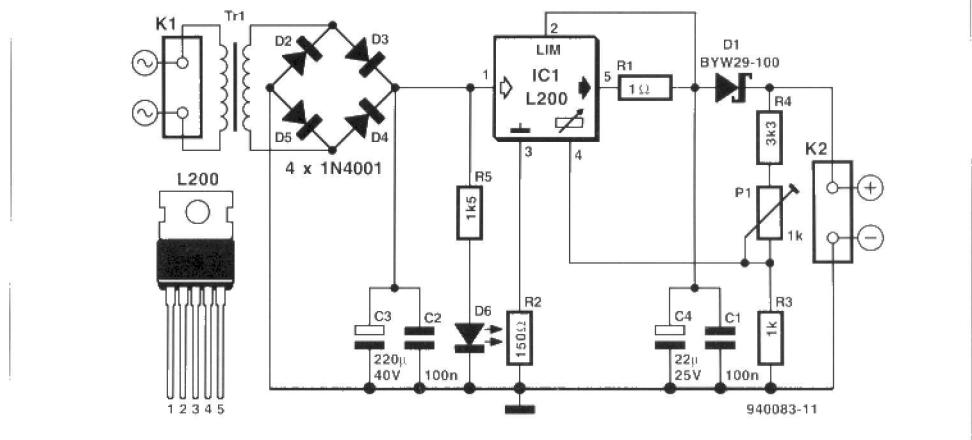


Fig. 1. Circuit diagram of the motive-battery charger.

after a while the voltage has dropped below 2.2 V, the charging current is switched on again.

## Circuit description

The mains voltage enters via K<sub>1</sub> (see Fig. 1) and the output (charging) voltage is available at K<sub>2</sub>. The mains voltage from K<sub>1</sub> is applied to a bridge rectifier, D<sub>2</sub>-D<sub>5</sub>, via transformer Tr<sub>1</sub>. Diode D<sub>6</sub> serves as on/off indicator; C<sub>3</sub> is a buffer capacitor, and C<sub>2</sub> decouples any r.f. noise voltage.

The heart of the circuit is a Type L200, IC<sub>1</sub>, from SGS Thomson. It is a programmable voltage and current regulator, housed in a five-pin case, which is reputed to be virtually indestructible. It can handle input voltages up to 40 V, with peaks up to 60 V, provides a current of up to 1.8 A, and is furnished with reliable thermal and short-circuit protection.

The L200 is a general-purpose chip, which in the present circuit is used as a current source that is switched off if the output (that is, charging) voltage

exceeds a certain value. This is done by comparing this voltage continuously with the 2.77 V reference potential at pin 4. The switch-off value is set with P<sub>1</sub>.

The peak output (charging) current is set by R<sub>1</sub>. When the current limiting is actuated, the voltage across R<sub>1</sub>, according to the manufacturer, is about 0.45 V, which gives a charging current of 450 mA.

Schottky diode D<sub>1</sub> prevents the battery discharging through IC<sub>1</sub> if there is a mains failure. In that case, the current is limited to that through R<sub>3</sub>, R<sub>4</sub> and P<sub>1</sub>, which amounts to only 3.5 mA.

Resistor R<sub>2</sub> protects IC<sub>1</sub> against the battery being connected with incorrect polarity. This is, however, only a short-term protection; if the battery remains connected with incorrect polarity, both IC<sub>1</sub> and C<sub>4</sub> will give up the ghost.

## Construction

The entire circuit, including the mains transformer, is intended to be built on the printed-circuit board in Fig. 2. Finishing the board is straightforward.

Note that a large space has been reserved on the board for a heat sink for IC<sub>1</sub>, because this chip will dissipate about 3 W. The IC must be electrically insulated from the heat sink with a ceramic washer and heat transfer paste.

When the board has been finished (see Fig. 3), it should be fitted in a well-insulated synthetic fibre case.

## Alignment

To set P<sub>1</sub> to the required voltage limits, a 12V battery and two multimeters are needed—see Fig. 4.

- Connect the charger to the mains and switch it on.
- Connect the battery to the output of the charger, with one of the multimeters (set to 1A d.c. range) in series with the + output terminal.
- Connect the other multimeter (set to 25 V range) across the output of the charger.
- Adjust P<sub>1</sub> for maximum output voltage.
- The battery is now being charged; observe the charging voltage.
- When the charging voltage reaches the desired maximum value, say, 13.5 V, slowly turn P<sub>1</sub> back until the charging current is zero.

If a laboratory power supply unit (PSU) is available, it may be used to simulate a battery by connecting a 27 Ω, 5 W resistor across its output terminals. Set the PSU output to 13.5 V, connect it to the output of the charger and adjust P<sub>1</sub> till the current just drops to zero.

In a rare case, it may happen that the required voltage limits can not be

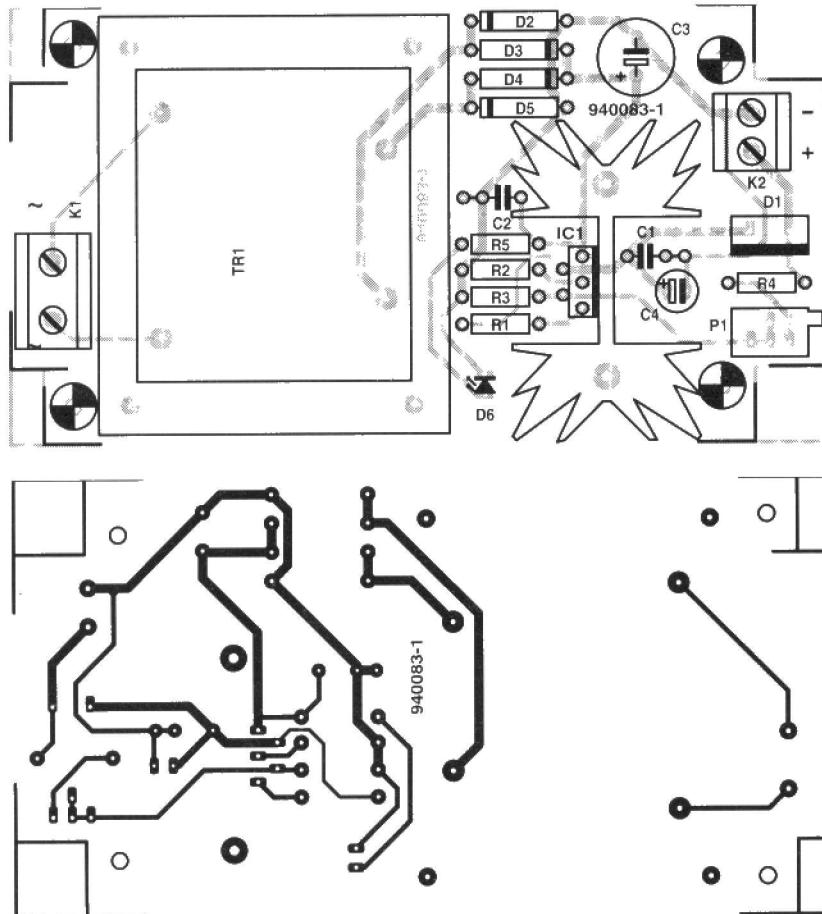


Fig. 2. Printed-circuit board for the motive-battery charger

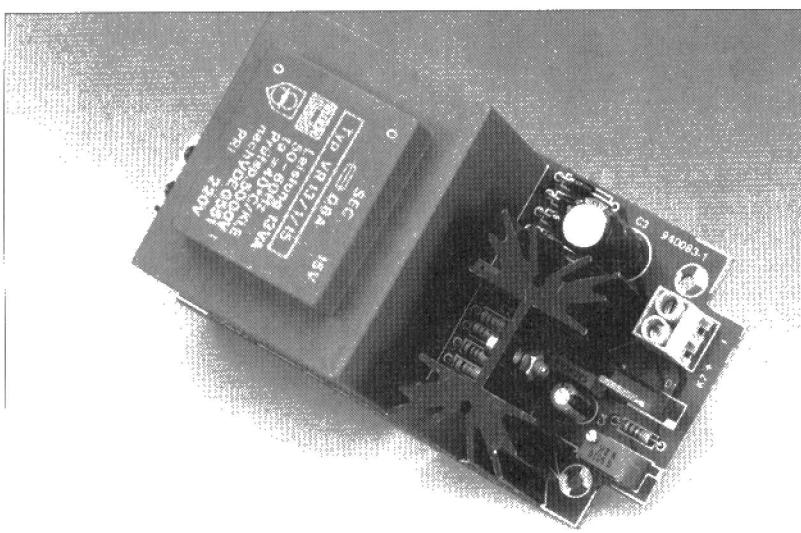


Fig. 3. Finished prototype board.

Produced and published by ELEKTOR  
ELECTRONICS (Publishing)

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**Director:** M.M.J. Landman  
**Editor-in-Chief/Publisher:** P.E.L. Kersmakers

**Commercial Manager:**  
K. van Noordenne

#### Distribution:

SEYMOUR  
1270 London Road  
LONDON SW16 4DH

Printed in the Netherlands by NDB,  
Zoeterwoude

#### Overseas editions:

FRANCE  
Elektor srl  
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**Editor:** G.C.P. Raedersdorf

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**Editor:** W. Marciniak

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**Editor:** F. Ferreira de Almeida

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28003 MADRID  
**Editor:** Agustin Gonzales Buelta

#### SWEDEN

Electronic Press AB  
Box 5505  
14105 HUDDINGE  
**Editor:** Bill Cedrum

set with  $P_1$ . This may be because the internal reference potential of the IC is slightly too high. This may be remedied by lowering the value of  $R_4$  slightly (to, say,  $2.2\text{ k}\Omega$ ).

#### Finally

Diode  $D_6$  may be fitted outside the enclosure and be connected to the board via two lengths of flexible, insulated circuit wire.

Use flexible, insulated wire of dia.  $\geq 0.75\text{ mm}$  for the connections between the battery and  $K_2$ . Use red wire for the +ve line and green or black wire for the -ve line. Suitable clamps can be obtained from car parts dealers or good hardware shops.

When disconnecting the battery, always take off the negative cable first and then the positive one. When connecting the battery, put on the positive cable first and then the negative one. These precautions will prevent a short circuit of the battery if the positive cable terminal accidentally touches the frame of the car or motorcycle.

#### Parts list

##### Resistors:

$R_1 = 1\ \Omega$   
 $R_2 = 150\ \Omega$   
 $R_3 = 1\text{ k}\Omega$   
 $R_4 = 2.2\text{ k}\Omega$  – see text  
 $R_5 = 1.5\text{ k}\Omega$   
 $P_1 = 1\text{ k}\Omega$  multturn preset

##### Capacitors:

$C_1, C_2 = 100\text{ nF}$   
 $C_3 = 220\text{ }\mu\text{F}, 40\text{ V}, \text{radial}$   
 $C_4 = 22\text{ }\mu\text{F}, 25\text{ V}, \text{radial}$

##### Semiconductors:

$D_1 = \text{BYW29-100}$   
 $D_2-D_5 = 1N4001$   
 $D_6 = \text{LED, red, } 5\text{ mm}$

##### Integrated circuits:

$IC_1 = \text{L200CV (5-pin)}$

##### Miscellaneous:

$K_1 = 2\text{-way terminal block, pitch } 7.5\text{ mm}$   
 $K_2 = 2\text{-way terminal block, pitch } 5\text{ mm}$   
 $Tr_1 = \text{short-circuit-proof mains transformer, } 15\text{ V, } 13\text{ VA}$   
Enclosure, synthetic fibre  
 $120\times65\times65\text{ mm (}4\frac{3}{4}\times2\frac{1}{2}\times2\frac{1}{2}\text{ in)}$   
Heat sink  $5\text{ K W}^{-1}$ , complete with  
fitting/insulating kit  
PCB Ref. 940083

[940083]

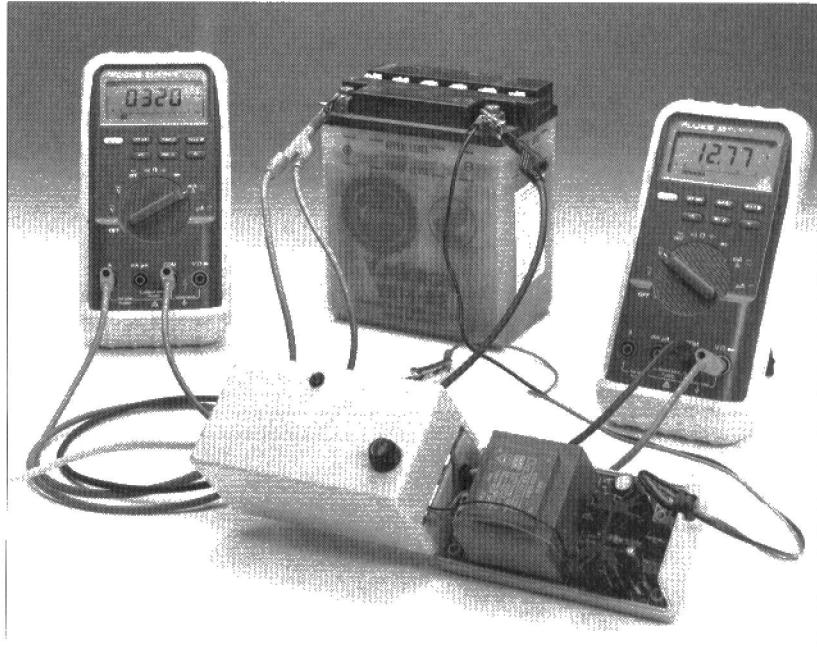


Fig. 4. During alignment, both voltage and current must be monitored.

# INTEGRATED A.F. AMPLIFIER - PART 2

Design by T. Giesberts

## Construction

The preamplifier section is intended to be built on the printed-circuit board shown in **Fig. 4**. Since the various connectors and controls (except S<sub>1</sub> and S<sub>2</sub>) are mounted directly on to the board, the completion of the board should not present any difficulties. Take care, however, not to overlook any of the wire bridges, which should be soldered in place first. Circuits IC<sub>5</sub> and IC<sub>6</sub> are intended to be fitted on a common heat sink, with insulating washers between the chips and the heat sink. The completed board is shown in **Fig. 6**.

The output amplifier is best built on the printed-circuit board shown in **Fig. 7**. Two of these boards are, of course, needed for a stereo version. As usual, start populating the board by soldering the wire bridges and small components in place. Pay particular attention to the polarity of C<sub>11</sub> and C<sub>13</sub>. It is advisable to solder R<sub>19</sub> and R<sub>20</sub> slightly off the board: this helps the cooling of these compo-

Main parameters	
Sensitivity (all inputs)	300 mV
Signal-to-noise ratio (input short-circuited) (input open-circuited)	100 dB (1 W into 8 Ω) 80 dB (1 W into 8 Ω)
Input impedance (all inputs)	47 kΩ
Slew rate	100 V μs <sup>-1</sup>
Line output impedance	100 Ω
Line output	1 V into 100 Ω
Tape output impedance	1 kΩ
Tape output	300 mV into 1 kΩ
Bandwidth (80 W into 4 Ω)	10 Hz - 70 kHz
Harmonic distortion (45 W into 8 Ω at 1 kHz) (85 W into 4 Ω at 1 kHz)	0.1% 0.2%
Maximum output power	85 W into 4 Ω 45 W into 8 Ω

nents. Use heavy-duty solder pins for all external connections to reduce the resistance to a minimum (remember that very high currents flow).

Mount T<sub>5</sub>, T<sub>6</sub> and T<sub>7</sub> on a common heat sink with a thermal rating of 0.6° W<sup>-1</sup>. Insulate the transistors from one another and from the heat

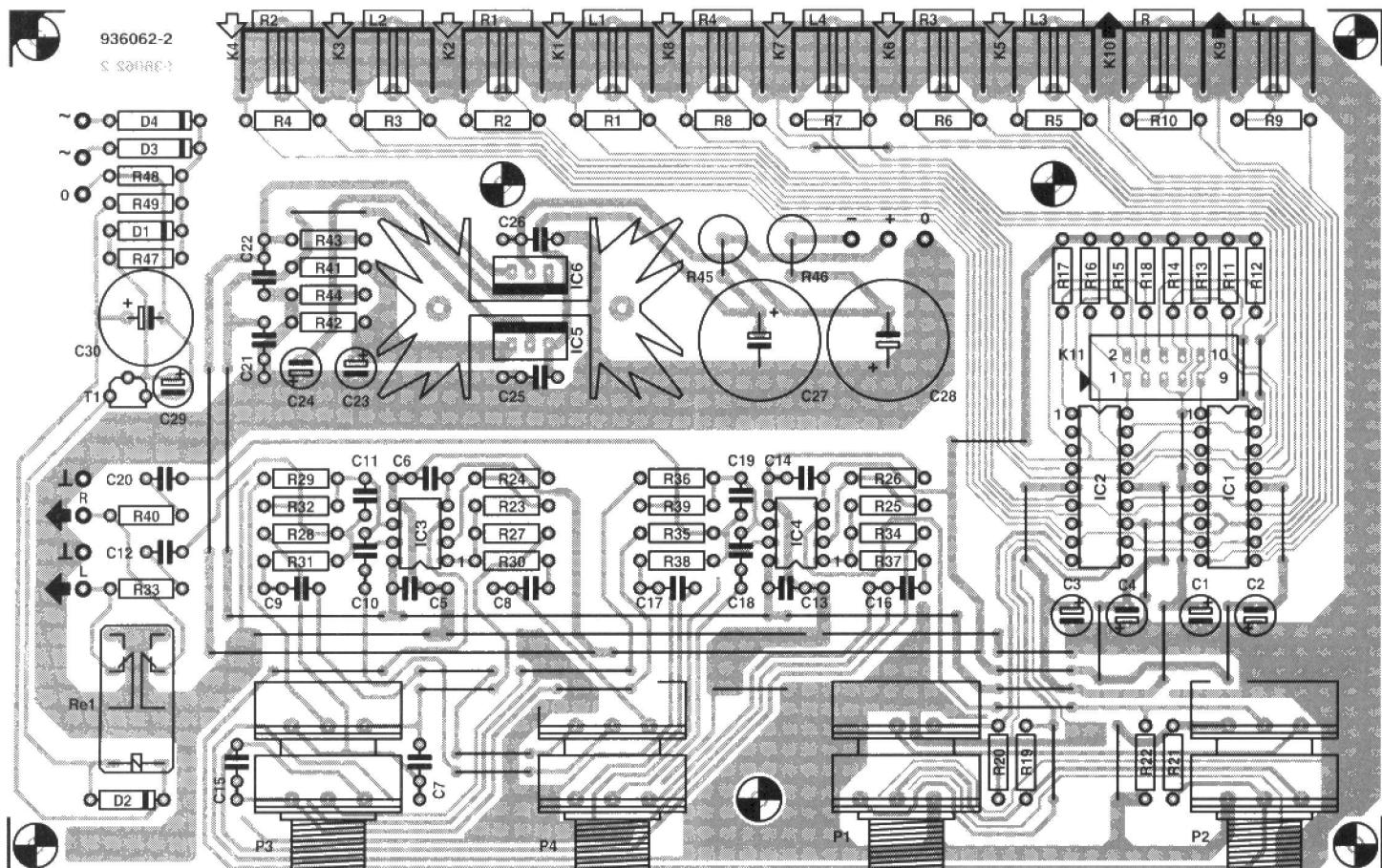


Fig. 4a. Printed-circuit board for the preamplifier section: component layout.

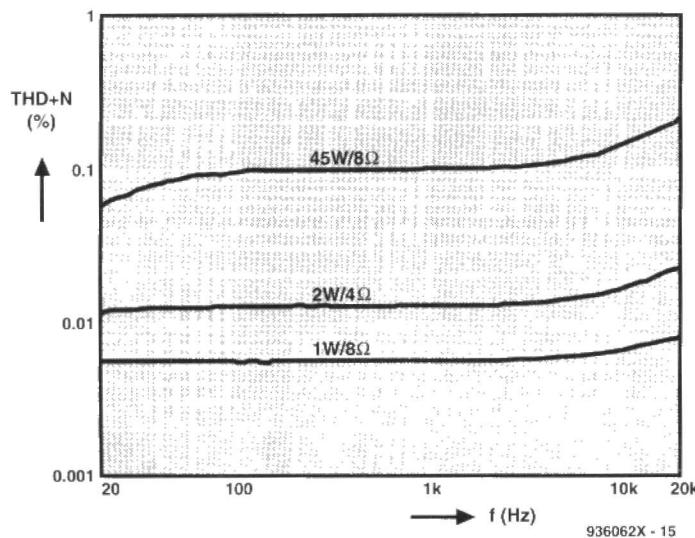


Fig. 5. Distortion plus noise vs frequency characteristic.

sink with ceramic washers (do not use mica or silicon types) and heat transfer paste.

## Assembly

Fit hc amplifiers and power supply in a standard 19 in. instrument case as shown in **Fig. 11**; the wiring diagram is shown in **Fig. 8**.

Fit the four 10000  $\mu$ F capacitors and the eight 0.1  $\Omega$ , 5 W, resistors

(power supply), and the series resistor for the on-off LED, on a separate piece of prototyping board.

Fix all the boards on insulated spacers to the bottom of the case.

Use insulated wire of at least 1.5 mm<sup>2</sup> diameter for the connections in the power suply and also for the power lines.

Link box header K<sub>11</sub> to S<sub>1</sub> and S<sub>2</sub> with flatcable (see **Fig. 1**, Part 1).

## Calibration

Set P<sub>1</sub> and P<sub>2</sub> on the output amplifier board to the centre of their travel. Short-circuit the input of the output amplifier and switch on the supply voltage. Connect a good-quality millivoltmeter across R<sub>19</sub> and R<sub>20</sub> in turn and adjust P<sub>2</sub> for a meter reading of 22 mV. The quiescent current is then around 100 mA. Next, adjust P<sub>1</sub> for an amplifier output of 0 V (or very nearly so). If that can not be achieved, replace T<sub>2</sub> by another transistor which makes it possible.

## Parts list

PREAMPLIFIER: Fig. 1 and Fig. 4

### Resistors:

- R<sub>1</sub>-R<sub>8</sub> = 47 k $\Omega$
- R<sub>9</sub>, R<sub>10</sub> = 1 k $\Omega$
- R<sub>11</sub>-R<sub>18</sub>, R<sub>29</sub>, R<sub>36</sub> = 10 k $\Omega$
- R<sub>19</sub>, R<sub>20</sub> = 2.2 k $\Omega$
- R<sub>21</sub>, R<sub>22</sub>, R<sub>32</sub>, R<sub>39</sub> = 1 M $\Omega$
- R<sub>23</sub>, R<sub>25</sub> = 4.22 k $\Omega$ , 1%
- R<sub>24</sub>, R<sub>26</sub> = 1.0 k $\Omega$ , 1%
- R<sub>27</sub>, R<sub>28</sub>, R<sub>34</sub>, R<sub>35</sub> = 2.7 k $\Omega$
- R<sub>30</sub>, R<sub>31</sub>, R<sub>37</sub>, R<sub>38</sub> = 1.8 k $\Omega$
- R<sub>33</sub>, R<sub>40</sub> = 100  $\Omega$
- R<sub>41</sub>, R<sub>43</sub> = 1.24 k $\Omega$ , 1%
- R<sub>42</sub>, R<sub>44</sub> = 10.7 k $\Omega$ , 1%
- R<sub>45</sub>, R<sub>46</sub> = 220  $\Omega$ , 5 W
- R<sub>47</sub> = 22 M $\Omega$
- R<sub>48</sub> = 4.7 k $\Omega$
- R<sub>49</sub> = 180  $\Omega$
- P<sub>1</sub>, P<sub>3</sub>, P<sub>4</sub> = 10 k $\Omega$ , linear, stereo

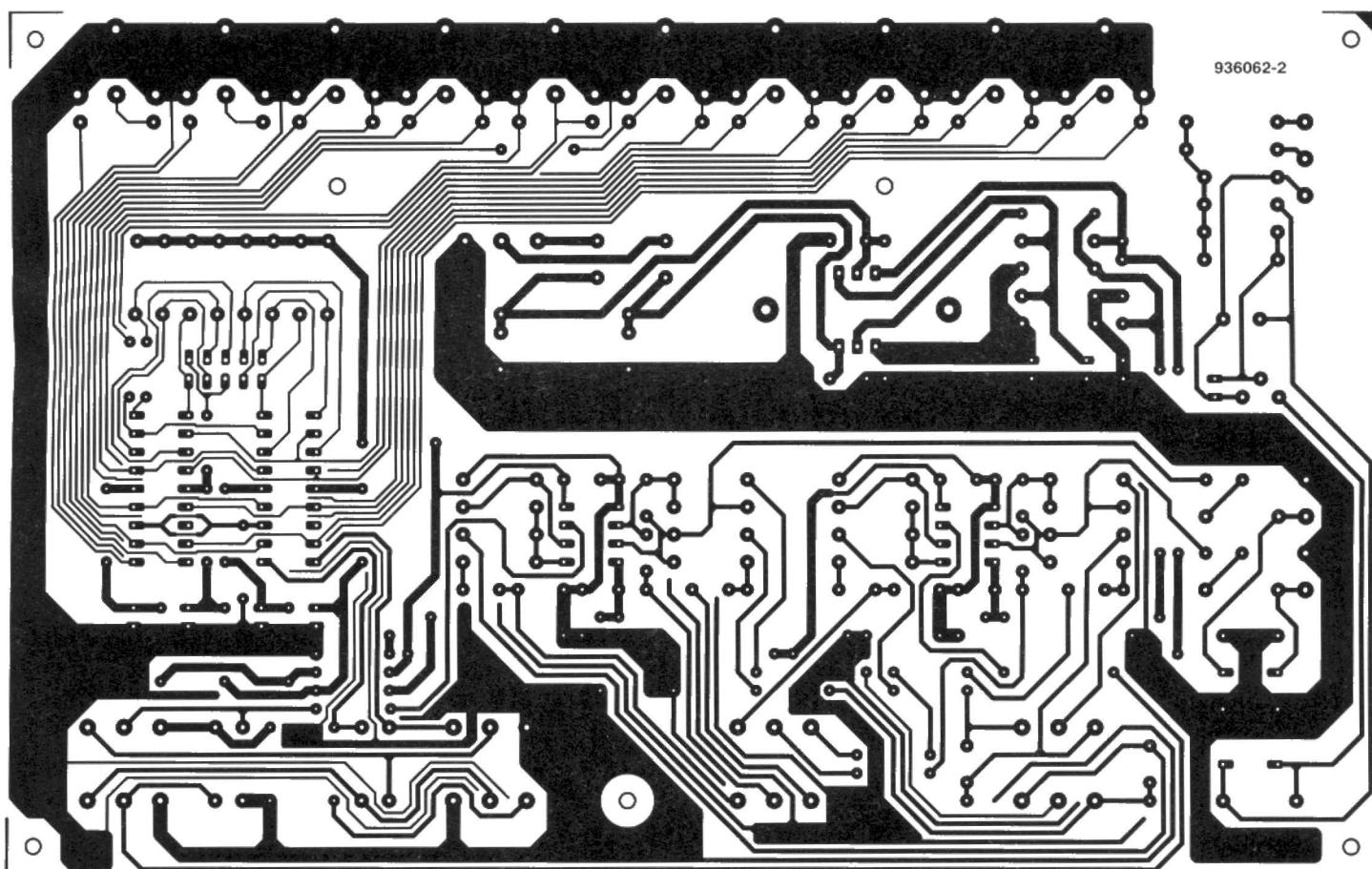


Fig. 4b. Printed-circuit for the preamplifier section: track layout.

P<sub>2</sub> = 10 kΩ, logarithmic, stereo

#### Capacitors:

C<sub>1</sub>-C<sub>4</sub> = 10 µF, 63 V, radial  
 C<sub>5</sub>, C<sub>6</sub>, C<sub>13</sub>, C<sub>14</sub>, C<sub>21</sub>, C<sub>22</sub>, C<sub>25</sub>,  
 C<sub>26</sub> = 100 nF

C<sub>7</sub>, C<sub>15</sub> = 180 nF  
 C<sub>8</sub>, C<sub>9</sub>, C<sub>16</sub>, C<sub>17</sub> = 68 nF  
 C<sub>10</sub>, C<sub>18</sub> = 3.9 nF  
 C<sub>11</sub>, C<sub>19</sub> = 47 pF  
 C<sub>12</sub>, C<sub>20</sub> = 2.2 µF, 50 V, polythene  
 C<sub>23</sub>, C<sub>24</sub> = 22 µF, 25 V, radial  
 C<sub>27</sub>, C<sub>28</sub> = 220 µF, 40 V, radial  
 C<sub>29</sub> = 2.2 µF, 63 V, radial  
 C<sub>30</sub> = 100 µF, 40 V, radial

#### Semiconductors:

D<sub>1</sub>, D<sub>2</sub> = 1N4148  
 D<sub>3</sub>, D<sub>4</sub> = 1N4003  
 T<sub>1</sub> = BC517

#### Integrated circuits:

IC<sub>1</sub>, IC<sub>2</sub> = LM1037  
 IC<sub>3</sub>, IC<sub>4</sub> = NE5532  
 IC<sub>5</sub> = LM317  
 IC<sub>6</sub> = LM337

#### Miscellaneous:

K<sub>1</sub>-K<sub>10</sub> = audio socket for PCB  
 mounting

K<sub>11</sub> = 10-way male box header and  
 female counterpart

S<sub>1</sub>, S<sub>2</sub> = 1-pole, 12-position rotary  
 switch

R<sub>e1</sub> = 2-contact change-over relay for  
 PCB mounting

Heat sink (IC<sub>5</sub>; IC<sub>6</sub>) 4° W<sup>-1</sup>

Insulating mounting kit for IC<sub>5</sub>, IC<sub>6</sub>  
 30 cm (12 in) 10-core flatcable  
 4 off extension spindle for P<sub>1</sub>-P<sub>4</sub>  
 PCB Ref. 936062-2

#### OUTPUT AMPLIFIER: Fig. 2 and 7

#### Resistors:

R<sub>1</sub>, R<sub>17</sub> = 1 kΩ  
 R<sub>2</sub> = 100 kΩ  
 R<sub>3</sub> = 2.7 kΩ  
 R<sub>4</sub> = 150 Ω  
 R<sub>5</sub>, R<sub>6</sub> = 470 kΩ  
 R<sub>7</sub>-R<sub>10</sub> = 2.2 MΩ  
 R<sub>11</sub> = 4.7 kΩ  
 R<sub>12</sub> = 5.6 kΩ  
 R<sub>13</sub>, R<sub>14</sub> = 560 Ω  
 R<sub>15</sub>, R<sub>16</sub> = 47 Ω  
 R<sub>18</sub> = 220 Ω  
 R<sub>19</sub>, R<sub>20</sub> = 0.22 Ω, 5 W  
 P<sub>1</sub> = 2.5 kΩ preset  
 P<sub>2</sub> = 250 Ω preset

#### Capacitors:

C<sub>1</sub> = 1 nF  
 C<sub>2</sub>, C<sub>3</sub>, C<sub>9</sub> = 1 µF  
 C<sub>4</sub> = 100 µF, 10 V, bipolar  
 C<sub>5</sub>, C<sub>6</sub> = 150 nF  
 C<sub>7</sub>, C<sub>8</sub> = 100 pF  
 C<sub>10</sub>, C<sub>12</sub> = 680 nF  
 C<sub>11</sub>, C<sub>13</sub> = 10 000 µF, 40 V, radial

#### Semiconductors:

T<sub>1</sub> = BC550C  
 T<sub>2</sub> = BC560C

T<sub>3</sub> = BC640

T<sub>4</sub> = BC639

T<sub>5</sub> = BD139

T<sub>6</sub> = BDV65B

T<sub>7</sub> = BDV64B

#### Miscellaneous:

Heat sink (T<sub>5</sub>-T<sub>7</sub>), 0.6 °C W<sup>-1</sup>

(160×75 mm)

Mounting insulating kits for T<sub>5</sub>-T<sub>7</sub>

PCB Ref. 936062-1

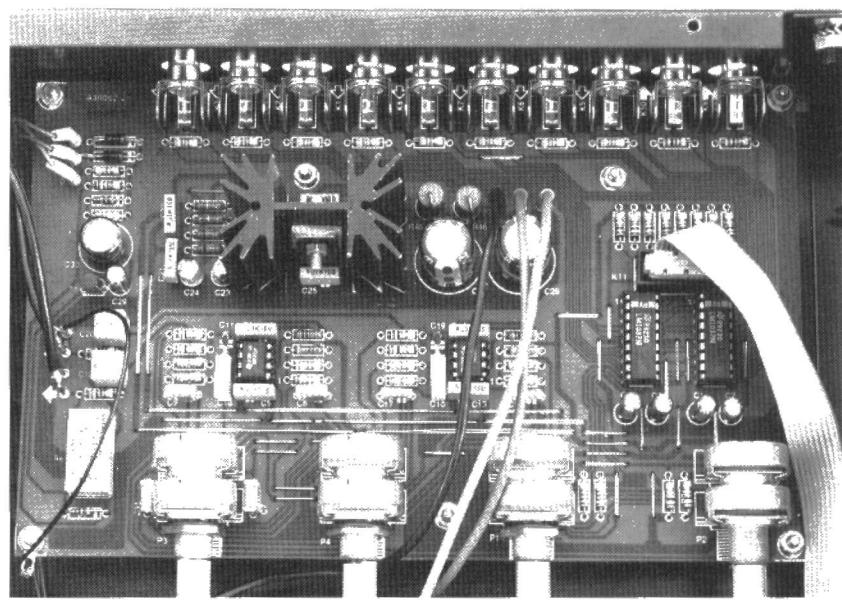


Fig. 6. Completed printed-circuit board for the preamplifier. The potentiometers are fitted with extension spindles.

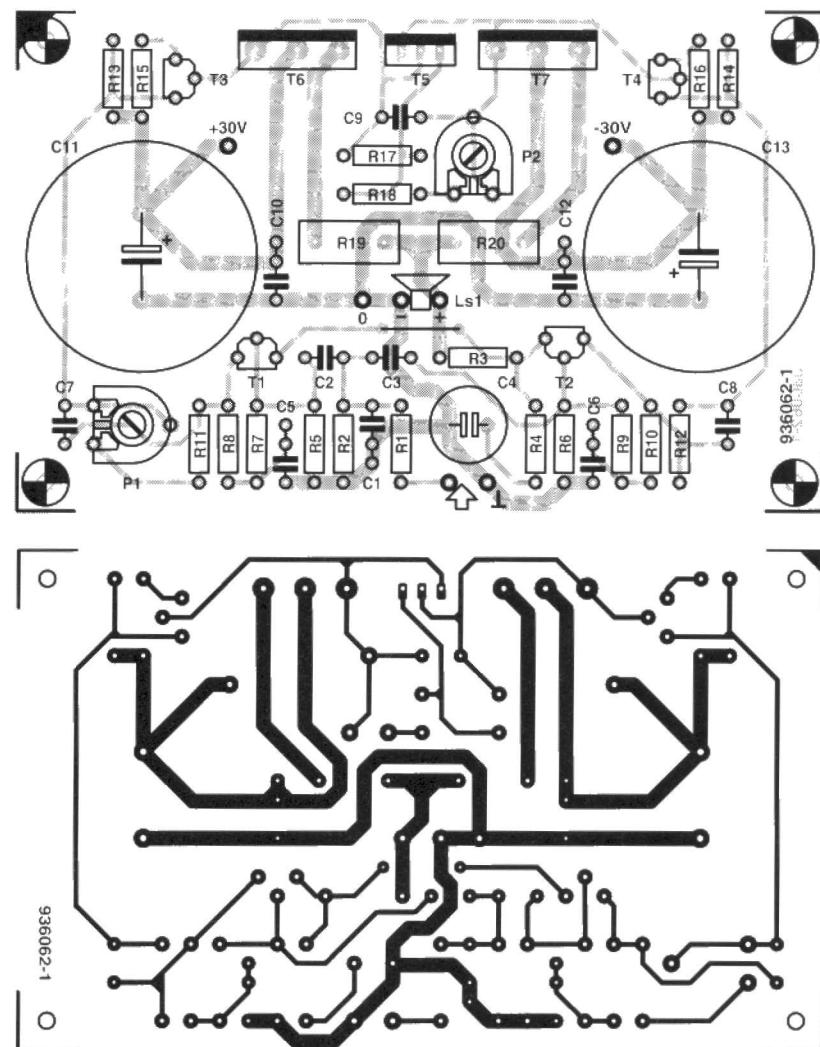


Fig. 7. Printed-circuit board for the output amplifier section.

POWER SUPPLY: Fig. 3

**Resistors:**

$R_1-R_8 = 0.1 \Omega$ , 5 W

$R_9 = 10 \text{ k}\Omega$

**Capacitors:**

$C_1-C_4 = 10\,000 \mu\text{F}$ , 50 V

**Semiconductors:**

$D_1$  = LED, low current

$B_1$  = bridge rectifier B200C35

$\text{Tr}_1$  = toroidal mains transformer,  
secondary  $2 \times 22 \text{ V}$ , 300 VA (mono),  
600 VA (stereo)

**GENERAL**

Standard 19 in, 2-unit high  
instrument case

Mains entry with integral fuses

Mains on/off switch with integral  
LED indicator

[936062]

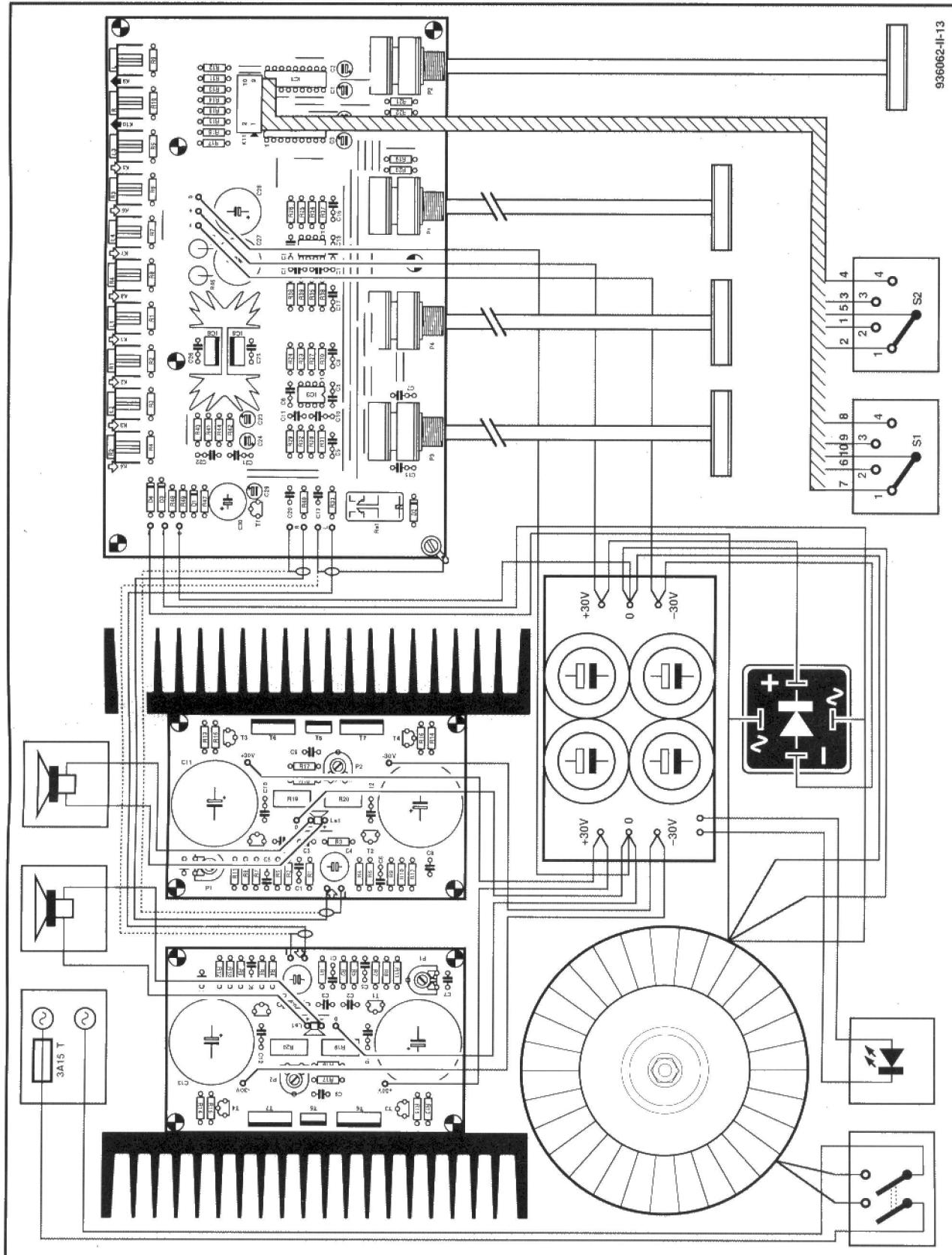


Fig. 8. Wiring diagram of the complete integrated amplifier.

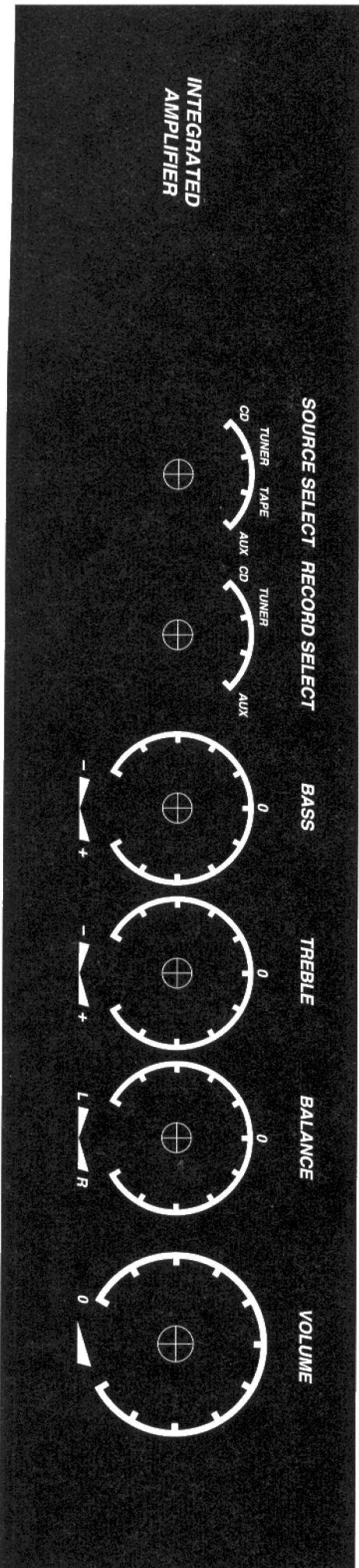


Fig. 9. Suggested front panel.

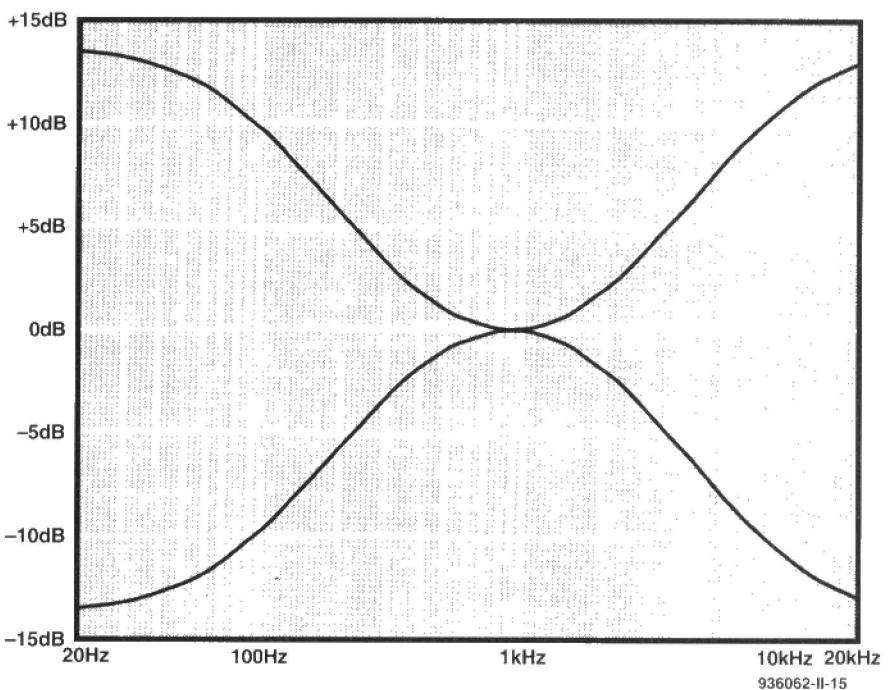


Fig. 10. Frequency characteristics of the amplifier with the tone control at its extreme settings

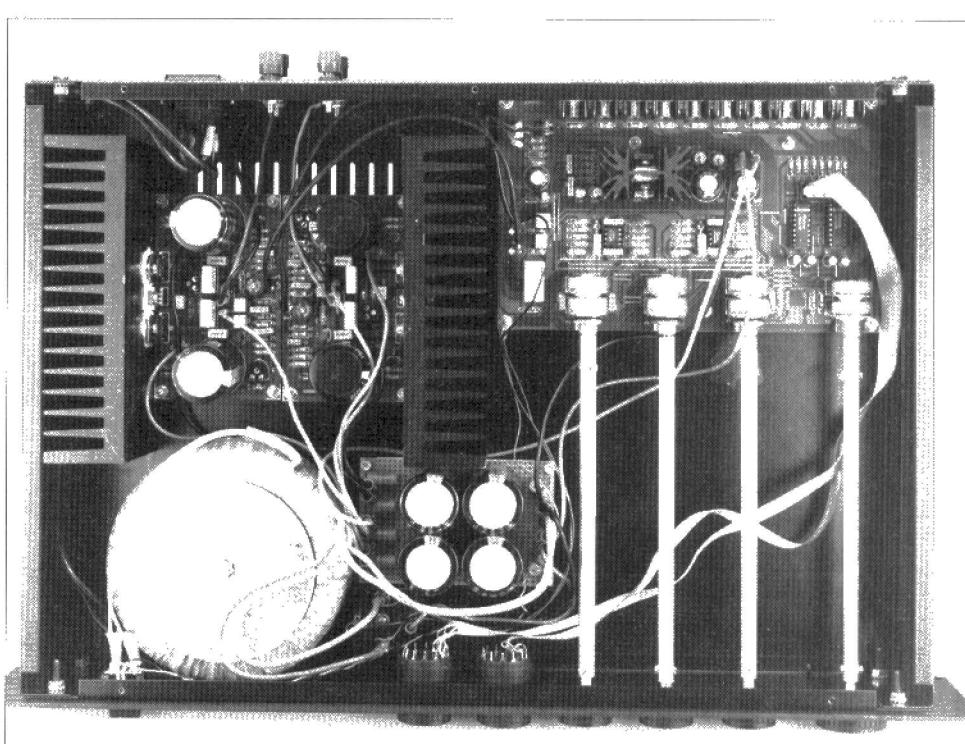


Fig. 11. Inside top view of the completed prototype amplifier.

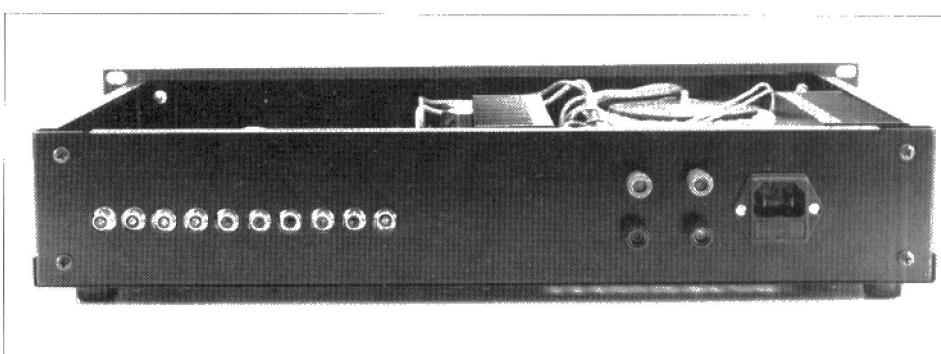


Fig. 12. Rear view of the integrated amplifier.

# TESTER FOR INFRA-RED REMOTE CONTROL

Design by A. Rietjens

**Modern audio and video systems, virtually without exception, use infra-red remote control. If one day (normally a Sunday) the remote control unit does not elicit a response from the associated equipment, the tester described will quickly establish the cause of failure (hopefully, it is just a flat battery)**

Modern domestic remote control units for radio, television and audio systems invariably use infra-red light to pass instructions to the receiver in the associated equipment. The transmitter, housed in a small, handheld box, uses an infra-red transmit diode, while the associated receiver, built in the audio or video equipment, uses an infra-red photo diode. When one of its control buttons is pressed, the transmitter emits a burst of high-frequency signals. Since humans can not see infra-red light, it is impossible for us to observe whether the transmitter does indeed emit signals. The present tester can detect these signals and at the same time give a general indication of their intensity and quality.

## How does it work?

Before the tester is detailed, a brief description of how an infra-red remote control works may be useful. The description is based on the frequently used Philips/Sony RC5 coding. Other manufacturers may use different coding techniques, but that does not invalidate the method of operation nor the tester.

Each burst of IR light emitted by the transmitter is 25 ms long and contains a 14-bit code word—see Fig. 1. Each burst of light is followed by an interval of about 90 ms. Each bit in the code word is superimposed on to a carrier of 36 kHz. The carrier is not symmetric: its logic '0' period is three times as long as its logic '1' period.

The tester contains an integrated decoder that detects the IR light and converts this into a train of digital bits. This train of data is used to give an indication of the quality of the light signals. This is based on the fact that the IR receiver will not function properly with (very) weak signals: capturing and synchronizing them will take longer than with strong signals. This time difference in processing gives an indication of the quality of the signals.

A full description of the RC5 coding is given in Ref. 1.

This is made possible by the fact that all IR remote control systems make use of a high frequency carrier. Low-frequency signals are filtered out and thus do not appear in the output. The detector output is a TTL signal that indicates whether or not HF signals are being received. That is, the level at the output varies in rhythm with the HF bursts that reach the photo diode: a high level means there is no h.f. signal, while a low level indicates that an HF signal is present.

The tester works on the principle that the pulses used in the test are

## Design of tester

The IR detector in the block schematic of the tester in Fig. 2 is a complete receiver that is able to filter from the IR light it receives only those signals that are associated with IR remote control.

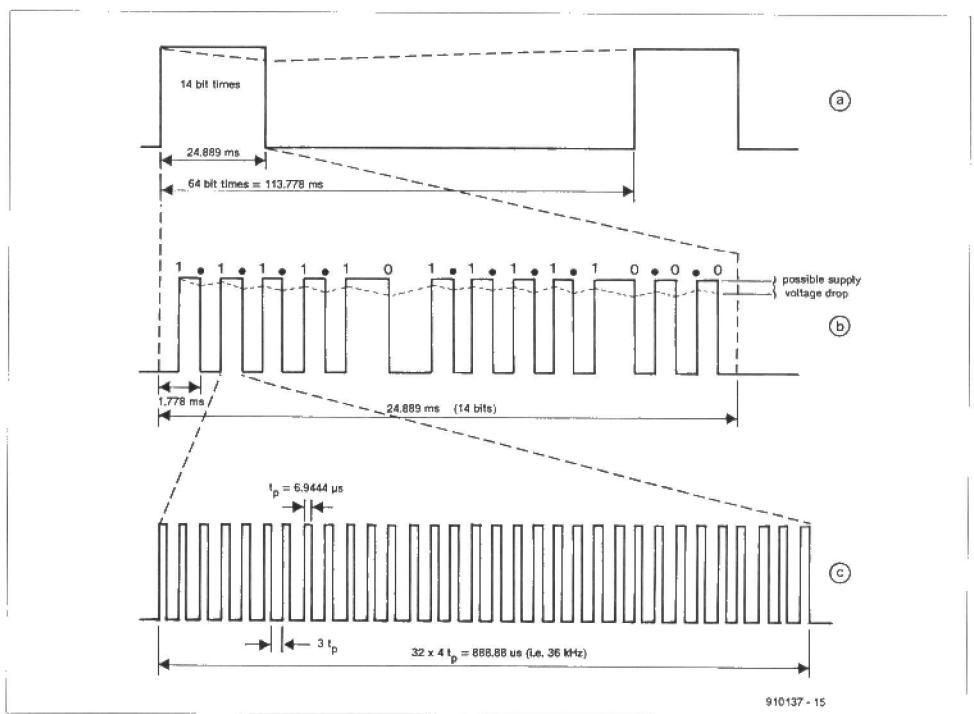


Fig. 1. How an RC5 command is modulated.

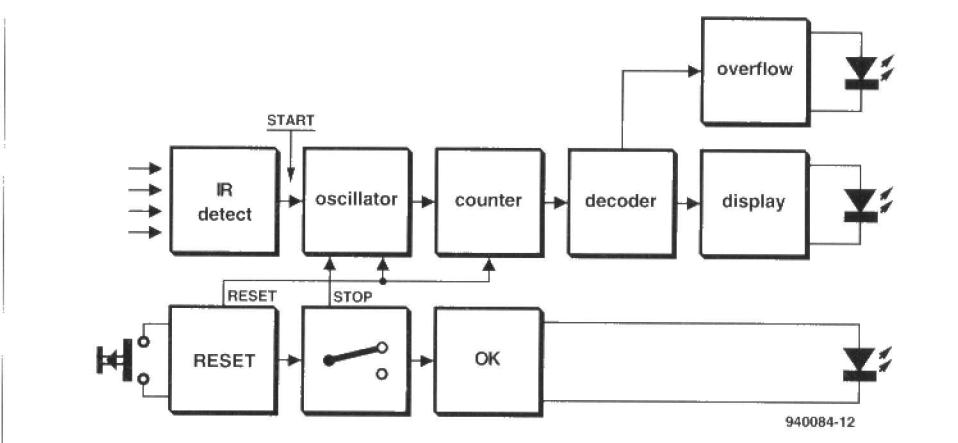


Fig. 2. Block diagram of the remote control tester.

identical. However, not only does the pulse train depend on which button is pressed on the transmitter, but the code varies even when the same button is pressed twice in succession. Fortunately, the header of each instruction is constant, and this is, therefore, used in the tester.

Even then, there is a slight difficulty: in some protocols the first bit is relatively long to enable the transmitter and receiver to synchronize. Because of this, the variation in length caused by

poor communication is very small, so that it gives no, or very little, idea of the quality of the signals. To bypass this difficulty, the tester has a change-over switch that enables either the first or the second bit to be selected.

Immediately a pulse train is received, the tester starts an oscillator. The number of pulses counted in the first (or second) bit is read, converted and then made visible on a display (a bar of LEDs).

The LED which indicates that a

pulse train has been received also functions as underflow indicator. There is also an overflow indicator. Both LEDs are useful during the calibration of the tester.

## Circuit description

To some extent, the circuit, whose diagram is shown in Fig. 3, is based on IC<sub>1</sub>. This chip contains both the oscillator and counter which are of paramount importance for measuring the

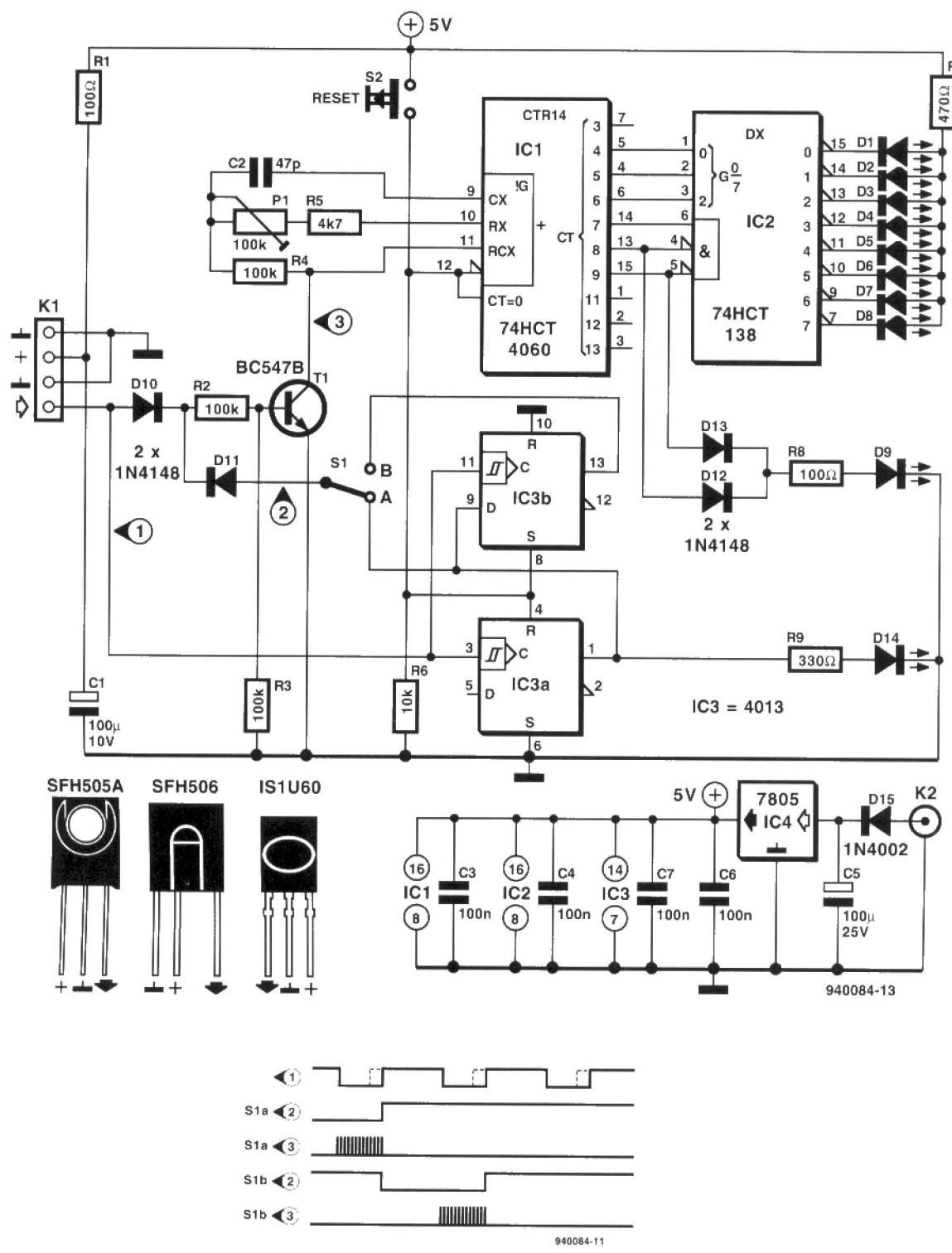


Fig. 3. Circuit diagram of the remote control unit tester.

pulse periods.

The integrated IR photo diode is connected to K<sub>1</sub>. The digital code converted from the incoming IR signals is applied to pin 1. A high logic level at this pin, applied to transistor T<sub>1</sub> via D<sub>2</sub> and potential divider R<sub>2</sub>-R<sub>3</sub>, causes the transistor to conduct. This results in the oscillator input (pin 11) of IC<sub>1</sub> being connected to earth.

The two bistables (flip-flops) in IC<sub>3</sub> determine which pulse will be measured. After a reset, the Q output (pin 1) of IC<sub>3a</sub> is low and that of IC<sub>3b</sub> (pin 13) is high. The leading edge of the digital input signal gives both bistables a clock pulse, on the receipt of the leading edge of which the level at pin 5 of IC<sub>3</sub> is read and applied to pin 1. After the first clock pulse, pin 1 is high because pin 9 is linked to the +5 V line. Diode D<sub>14</sub> then lights to indicate that the first data pulse has been received. Pin 13 is kept low because pin 9 is held low by pin 1 at the instant the leading edge of the clock pulse is received. When the second clock pulse is received, pin 9 also goes high, so that from the third clock pulse onward both Q outputs are high.

The oscillator and counter in IC<sub>1</sub> operate only when transistor T<sub>1</sub> is off. This is the case only when the anodes of D<sub>10</sub> and D<sub>11</sub> are low. As far as D<sub>10</sub> is concerned, this is so every time a pulse arrives at pin 1 of K<sub>1</sub>. In the case of D<sub>11</sub>, it depends on the position of jumper S<sub>1</sub>. The transistor is off during the first data pulse with the jumper in position A, and during the second data pulse with S<sub>1</sub> in position B. During all subsequent data pulses, the transistor conducts. In the timing diagram in Fig. 3, signals 2 and 3 (S<sub>1a</sub>) are relevant when S<sub>1</sub> is in position A, and signals 2 and 3 (S<sub>1b</sub>) when the jumper is in position B.

Only outputs Q<sub>4</sub>-Q<sub>9</sub> of the counter are used. Pins 4, 5 and 6 are linked to the three inputs of 3-to-8 converter IC<sub>2</sub>. This chip is enabled when pin 14 of IC<sub>1</sub> is high and pins 13 and 15 are low. This condition is indicated by one of diodes D<sub>1</sub>-D<sub>8</sub> lighting. This arrangement means that measurements take place only during the second half of the period of the data pulse. Pulses that are shorter than half of their original duration are so mutilated that they are unusable. If more than eight clock pulses occur during half the period, the clock frequency is too high and an overflow takes place, whereupon D<sub>9</sub> lights. Either pin 13 or pin 14 or both are then high. This results in IC<sub>2</sub> being disabled and none of D<sub>1</sub>-D<sub>8</sub> lights. The



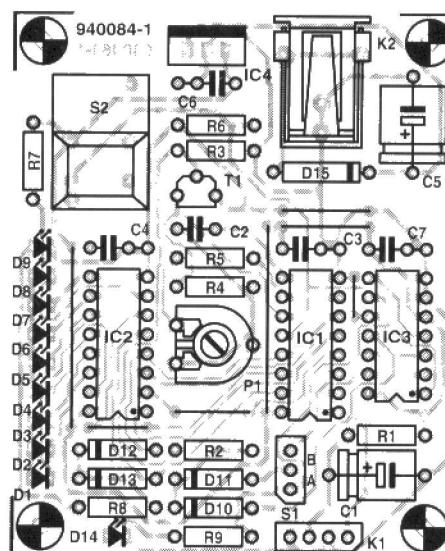
oscillator frequency, which is determined by R<sub>5</sub>, C<sub>2</sub> and P<sub>1</sub>, can be lowered with P<sub>1</sub> to ensure that the requisite number of pulses happen during the measurement period.

Three different types of photo diode may be used; the pinouts of all three are given in Fig. 3.

Power is obtained from a 9 V, 250 mA mains adaptor whose output is regulated by IC<sub>4</sub>. The circuit is protected against incorrect connection of the mains adaptor by D<sub>15</sub>.

## Construction

The tester is intended to be built on the printed-circuit board shown in Fig. 4.



As usual, commence by soldering the five wire bridge in place, followed by the smaller components. The design of the board allows the use of either a digitast switch or a data switch. These are slightly dearer than a standard push button type, but they are more reliable and are easily fitted.

The photo diode is soldered to the holes marked K<sub>1</sub>; pin 1 must go to the hole nearest the slanting line of the symbol.

## Alignment

When the board is finished, connect the mains adaptor to it and set P<sub>1</sub> to maximum resistance; the oscillator then generates its lowest frequency. Set jumper S<sub>1</sub> to position A. When the reset is pressed, all LEDs should be off. Press one button on the remote control transmitter, whereupon at least D<sub>14</sub> should light. (It is advisable to fit new batteries in the remote control transmitter before calibrating the tester). If it does not, check the power supply and the position of S<sub>1</sub>.

If D<sub>14</sub> lights, one of D<sub>1</sub>-D<sub>9</sub> will also light. If D<sub>9</sub> lights or flickers, there is an overflow. In that case, set S<sub>1</sub> to position B, reset the tester and press one of the buttons on the remote control transmitter. If this does not result in D<sub>14</sub> going out, reset S<sub>1</sub> to position A and replace C<sub>2</sub> by a 470pF capacitor. If this still does not work, there is almost certainly a defect in the circuit, which can only be found by careful checking and rechecking.

Assuming that all works well, hold the tester near the transmitter and adjust P<sub>1</sub> until D<sub>7</sub> or D<sub>8</sub> lights. Holding

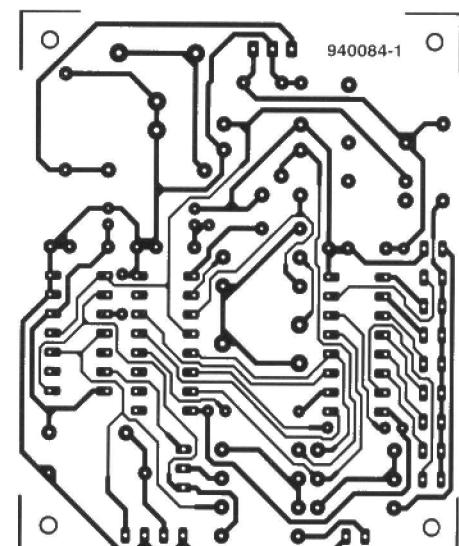


Fig. 4. Printed circuit board for the remote control unit tester.

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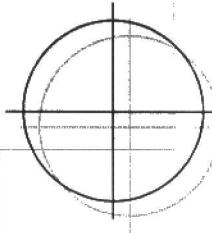
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### Integrated circuits:

IC<sub>1</sub> = 74HCT4060

IC<sub>2</sub> = 74HCT138

IC = 4013 — 1C3

IC<sub>4</sub> = 7805

### Miscellaneous:

K<sub>2</sub> = mains adaptor connector

S<sub>1</sub> = jumper

S<sub>2</sub> = digitast, data switch or push button switch

PCB Ref. 940084

[940084]

Ref. 1: Elektor Electronics, January 1992, p. 60

the tester at greater and greater distances from the transmitter will cause different LEDs to light: this proves that the tester operates correctly. If it gives varying results, set S<sub>1</sub> to position B.

Finally, bear in mind to press the reset button before each measurement.

### Parts list

#### Resistors:

R<sub>1</sub>, R<sub>8</sub> = 100 Ω

R<sub>2</sub>, R<sub>3</sub>, R<sub>4</sub> = 100 kΩ

R<sub>5</sub> = 4.7 kΩ

R<sub>6</sub> = 10 kΩ

R<sub>7</sub> = 470 Ω

R<sub>9</sub> = 330 Ω

P<sub>1</sub> = 100 kΩ preset

#### Capacitors:

C<sub>1</sub> = 100 pF, 10 V

C<sub>2</sub> = 47 pF

C<sub>3</sub>, C<sub>4</sub>\*, C<sub>6</sub>, C<sub>7</sub> = 100 nF

C<sub>5</sub> = +100 pF, 25 V

\* see text

#### Semiconductors:

D<sub>1</sub>–D<sub>9</sub>, D<sub>14</sub> = LED, red

D<sub>10</sub>–D<sub>13</sub> = 1N4148

D<sub>15</sub> = 1N4002

T<sub>1</sub> = BC547B

K<sub>1</sub> = Photo diode, SFH505, SFH506-36 or IS1U60

14 ABOVE MEAN 0.2 43A OF 4.70F

# COMPUTER PSU MONITOR

Design by K. Walraven

A circuit is described for continuously monitoring the various power supply lines in computers. It will also detect spikes (other than RF.) on these lines.

The monitor checks that the  $\pm 5$  V and  $\pm 12$  V supply voltages to a computer are within  $\pm 5\%$  of their nominal value. It will also detect spikes of a couple of hundreds of nanoseconds, but its operational amplifiers are too slow to detect RF interference.

The circuit is housed on a card that is intended to be inserted into one of the free ports of the computer. This

has the advantage that it is always present and that the voltages are monitored close to the computer's mother board.

Each supply voltage may be too low, all right, or too high. Each of these states is indicated by an LED. The all right state has a fourth LED which has a memory that registers whether the all right LED has been off at least once

after a system reset. If so, there is a spike on the supply line.

The LEDs and the reset control may be brought to the front panel via a length of ribbon cable to enable monitoring to take place at the front rather than at the rear of the computer. The board has been designed to make this a simple modification.

## Detector/indicator circuit

The circuit of the monitor (Fig. 1) consists of four similar detector circuits, a power supply and 16 indicator LEDs.

To keep the circuit simple, the supply voltages to be monitored are brought down to a standard level of 1.25 V. Reference potentials REF+ and REF- are symmetrically centred on this standard voltage; they differ from it by a margin that is preset with P1. With component values as specified, this margin is 0–10%.

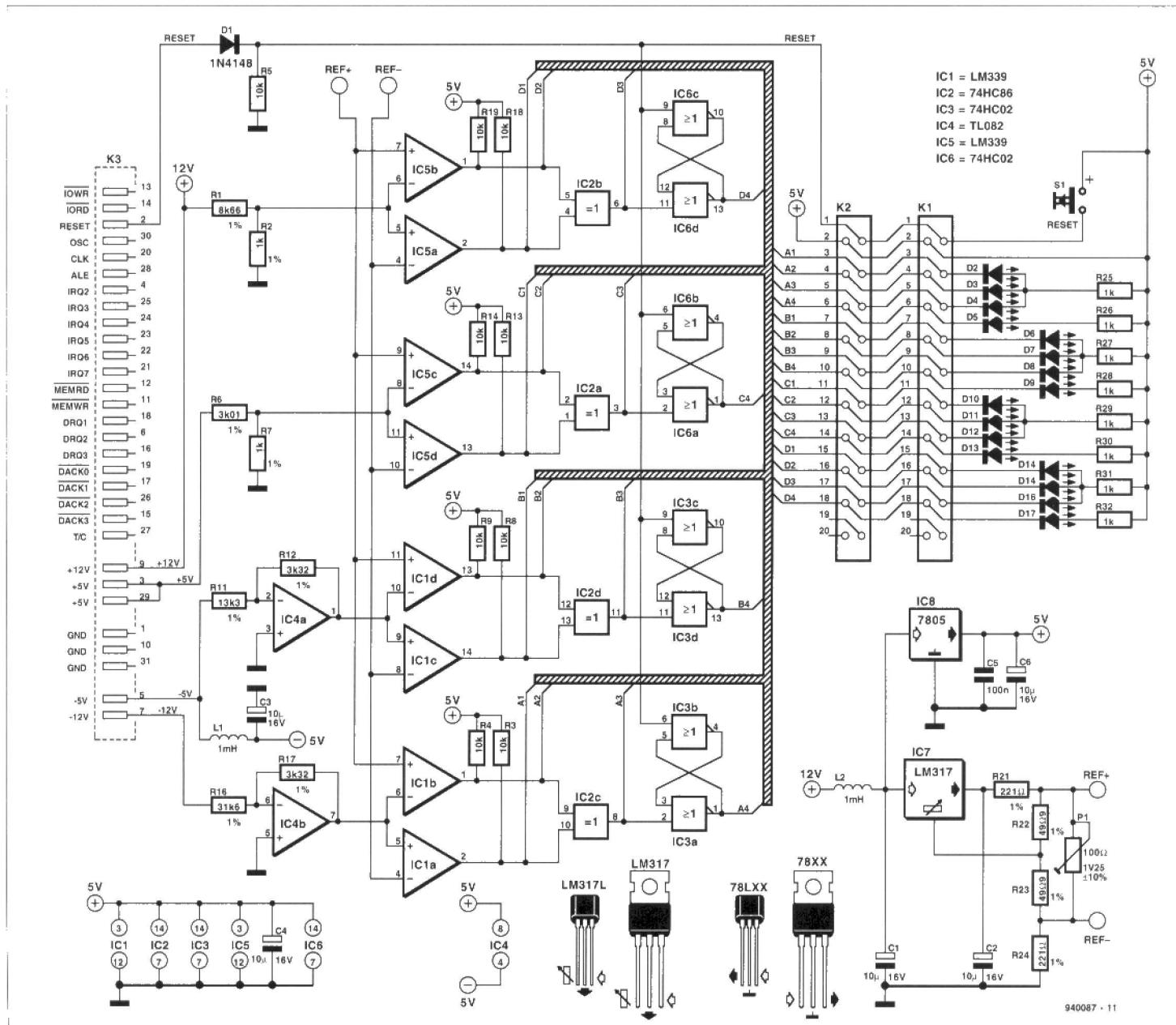


Fig. 1. Circuit diagram of the PSU monitor.

The +5 V and +12 V supply voltages are reduced to 1.25 V by resistors R<sub>6</sub>, R<sub>7</sub> and R<sub>1</sub>, R<sub>2</sub> respectively. The -5 V and -12 V voltages are lowered by resistors R<sub>11</sub>, R<sub>12</sub> and inverter IC<sub>4a</sub>, and R<sub>16</sub>, R<sub>17</sub> and inverter IC<sub>4b</sub> respectively.

The standard level is compared with reference voltages by two comparators, say, IC<sub>1a</sub> and IC<sub>1b</sub>. If the levels correspond, the outputs of the comparators are high and the (red) LEDs connected to the outputs remain off. Since the in-

puts to the XOR gate, IC<sub>2c</sub>, following the opamps, are then high, the output of the gate is low, which causes the associated (green) LED to light.

The last stage of each detector circuit is a bistable (flip-flop) formed by two NOR gates (as, for instance, IC<sub>3a</sub> and IC<sub>3b</sub>). The bistable is reset by pressing S<sub>1</sub>. A system reset of the computer also resets the bistable. The LED connected to the Q output of the bistable goes out after the reset. Diode

D<sub>1</sub> prevents a reset of the entire computer when S<sub>1</sub> is pressed.

If the level at the set input of, say, IC<sub>3a</sub> (pin 2), goes high, possibly because the supply voltage drops or rises briefly, the bistable is set and the fourth (yellow) LED lights. The LED stays on until the next reset. To ensure that all bistables are reset after the computer has been switched on, they are also connected to the reset circuit in the computer.

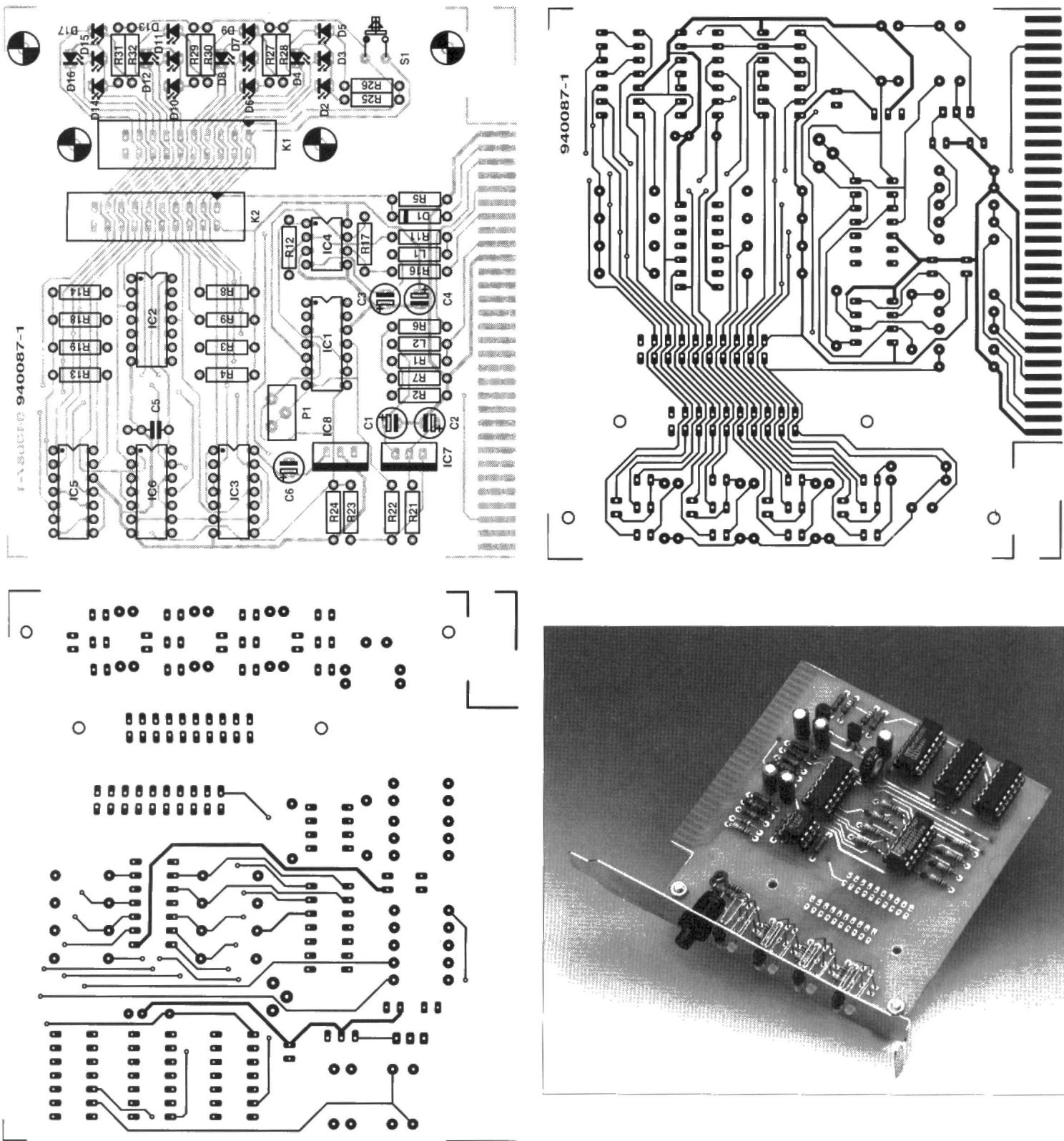


Fig. 2. Printed-circuit board for the PSU monitor. Photograph shows completed prototype.

The 5 V power supply for the monitor is derived from a 12 V source regulated by IC<sub>8</sub>. The -5 V supply for IC<sub>4</sub> is derived from the computer. A small inductor, L<sub>1</sub> or L<sub>2</sub>, as the case may be, is connected in series with the -5 V and +12 V lines to prevent the buffer capacitors in the power supply suppressing spikes (which would prevent the detectors sensing them).

Regulator IC<sub>7</sub> provides the reference voltages. This IC has an internal reference of 1.25 V, which here is present across R<sub>21</sub> and R<sub>22</sub>. Since R<sub>23</sub> and R<sub>24</sub> have the same value as R<sub>21</sub> and R<sub>22</sub> respectively, the voltage across them is also 1.25 V. When P<sub>1</sub> has a value of 0 Ω, the potential across both R<sub>21</sub> and R<sub>24</sub> is 1.25 V. The levels at REF+ and REF- are then the same (1.25 V). When P<sub>1</sub> is set to its maximum value, the potential across R<sub>21</sub> and R<sub>24</sub> is 1.13 V. The level at REF+ is then 1.37 V and that at REF- is 1.13 V.

## Construction

The monitor is intended to be built on a double-sided printed-circuit board as shown in Fig. 2 (which is unfortunately not available ready made). A single-sided board proved not feasible, because it would require more than 25 wire bridges. The design of the board ensures that the LEDs (slightly bent) protrude outside after the board has been slotted into the computer. As mentioned earlier, the section of the board on which the LEDs and the reset switch are located may be cut off and brought to the front of the computer via a length of ribbon cable terminated in headers. The cut must run in between K<sub>1</sub> and K<sub>2</sub>, but the cutting must ensure

that the two fixing holes for the support bracket near K<sub>1</sub> remain on the plug-in board. If this option is not used, headers K<sub>1</sub> and K<sub>2</sub> are not required.

When the board has been finished, the monitor is ready for use after P<sub>1</sub> has been adjusted as desired. Normally, the circuits work correctly with a tolerance of 5%, which is set as follows. After the board has been inserted into the computer and this has been switched on, connect a digital multimeter between earth and pin 4 of IC<sub>5</sub> and adjust P<sub>1</sub> for a meter reading of 1.19 V. The potential at pin 7 of IC<sub>5</sub> should then be 1.31 V. If setting these values is not possible, the LM317 used is not sufficiently accurate. In that case, replace it by an LT117 from Linear Technology which has a tolerance of only 1%.

Note that if the set limits are tight, it may happen that after S<sub>1</sub> has been pressed, the yellow LEDs seem to stay on. This is caused by brief supply voltage variations that occur regularly in computers. The reaction of the red LEDs is so fleeting that it appears as if they remain off. Provided the computer functions properly, it is advisable in such a case to set the limits with P<sub>1</sub> rather wider.

## Parts list

### Resistors:

R<sub>1</sub> = 8.66 kΩ, 1%  
 R<sub>2</sub>, R<sub>7</sub> = 1 kΩ, 1%  
 R<sub>3</sub>–R<sub>5</sub>, R<sub>8</sub>, R<sub>9</sub>, R<sub>13</sub>, R<sub>14</sub>, R<sub>18</sub>,  
 R<sub>19</sub> = 10 kΩ  
 R<sub>6</sub> = 3.01 kΩ, 1%  
 R<sub>11</sub> = 13.3 kΩ, 1%  
 R<sub>12</sub>, R<sub>17</sub> = 3.32 kΩ, 1%

R<sub>16</sub> = 31.6 kΩ, 1%  
 R<sub>21</sub>, R<sub>24</sub> = 221 Ω, 1%  
 R<sub>22</sub>, R<sub>23</sub> = 49.9 Ω, 1%  
 R<sub>25</sub>–R<sub>32</sub> = 1 kΩ  
 P<sub>1</sub> = 100 Ω preset, vertical

### Capacitors:

C<sub>1</sub>–C<sub>4</sub> = 10 μF, 16 V, radial  
 C<sub>5</sub> = 100 nF

### Inductors:

L<sub>1</sub>, L<sub>2</sub> = 1 mH

### Semiconductors:

D<sub>1</sub> = 1N 4148  
 D<sub>2</sub>, D<sub>3</sub>, D<sub>6</sub>, D<sub>7</sub>, D<sub>10</sub>, D<sub>11</sub>, D<sub>14</sub>  
 D<sub>15</sub> = LED, 3 mm, red\*  
 D<sub>4</sub>, D<sub>8</sub>, D<sub>12</sub>, D<sub>16</sub> = LED, 3 mm, green\*  
 D<sub>5</sub>, D<sub>9</sub>, D<sub>13</sub>, D<sub>17</sub> = LED, 3 mm, yellow\*

\* high efficiency

### Integrated circuits:

IC<sub>1</sub>, IC<sub>5</sub> = LM339 or LP339  
 IC<sub>2</sub> = 74HC86 or HCT86  
 IC<sub>3</sub>, IC<sub>6</sub> = 74HC02 or HCT02  
 IC<sub>4</sub> = TL082  
 IC<sub>7</sub> = LM317 or LM317L – see text  
 IC<sub>8</sub> = 7805 or 78L05

### Miscellaneous:

K<sub>1</sub>, K<sub>2</sub> = 20-pin straight box header  
 see text  
 S<sub>1</sub> = press button switch with make contact  
 PC insertion card support bracket,  
 e.g., Fisher KHPCL (see Fig. 3)  
 or Eurodis No. Spe22833.

[940087]

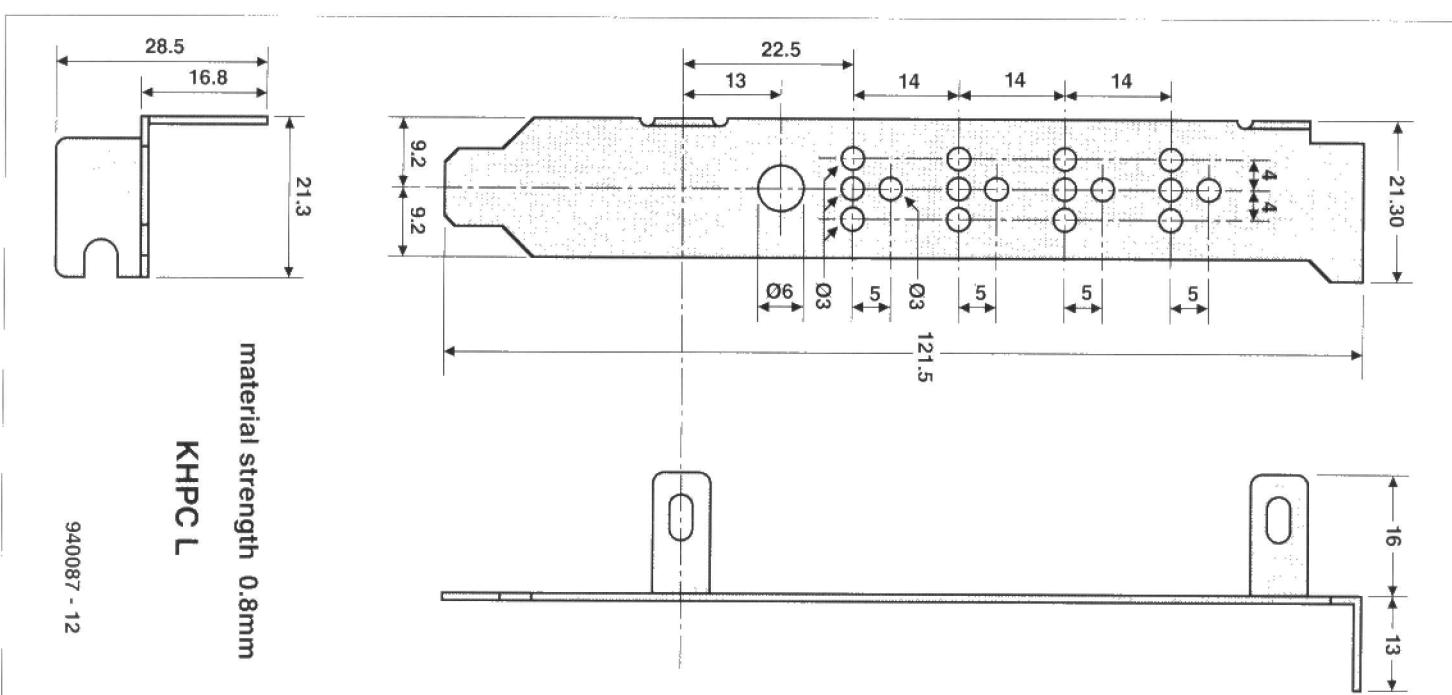


Fig. 3. Template (1:1) of the support bracket showing how the LEDs should be fitted.

# STABLE D.C.-D.C. CONVERTER

Design by L. Lemmens

**The very compact converter produces a stable 5 V direct voltage supply from an input of 2.5 V, and is thus eminently suitable for use in portable equipment.**

Battery-operated equipment that contains digital circuits often requires a supply voltage of 5 V. If stabilization of the supply is required, the battery voltage needs to be at least 6 V owing to the drop across the regulator. Standard regulators can not be used, of course, since these require an input voltage 3 V higher than the output voltage. Even a low-drop regulator needs a voltage drop of not less than 0.4 V. And then there is the recurring problem of space being limited to no larger than for, say, two HP7 (AA, UM3, Mignon) batteries. There are then two ways the designer can take. One is to be satisfied with a supply of 2–3 V and design the electronics accordingly. This is, however, not always possible. The other way is to use a d.c.-d.c. converter as described in this article.

In spite of its compactness, the converter can supply 100 mA at 5 V from an input of 2.5 V.

## MAX660

The converter is based on an IC type

MAX660 from Maxim. It operates on the charge pump principle and fulfills two functions: it can convert a positive voltage into a negative one, and it can double the voltage at its input. It is, in fact, a pin-compatible successor to the ICL7660 with the output current uprated to 100 mA. The internal setup of the IC is shown in Fig. 1.

The charge pump principle depends on the rapid charging and discharging of a capacitor, and this requires switches and an oscillator.

An oscillator is contained in the MAX660 and it is followed by a binary scaler. The standard oscillator frequency of 10 kHz can be altered via pin 7. This pin is also used if an external oscillator is employed. The internal voltage regulator can be disabled via pin 6 if operation from a very low input voltage is desired.

The (electronic) switches are formed by four MOSFETs. Since the substrates of the FETs on the right always need a negative voltage with respect to the source (to prevent leakage via the substrate), a logic network is provided. In combination with the

voltage level translator, this network ensures that the substrate is always at the correct potential.

The action of the pump will be described with reference to Fig. 2, in which the FETs have been drawn as normal switches. Note that the connections seem different from those in Fig. 1; this is because here pin 5 functions as ground, pin 3 as input and pin 8 as output. Capacitor C<sub>3</sub> functions as pump, while C<sub>1</sub> is the (external) output capacitor.

The oscillator voltage causes switch pairs S<sub>2</sub>-S<sub>4</sub> and S<sub>1</sub>-S<sub>3</sub> to be opened and closed in turn. When S<sub>2</sub> and S<sub>4</sub> are closed, C<sub>3</sub> is charged very rapidly to the battery voltage. When S<sub>1</sub> and S<sub>3</sub> are closed (S<sub>2</sub> and S<sub>4</sub> are then open), C<sub>3</sub> is connected in series with the battery via S<sub>3</sub>. At the same time, C<sub>1</sub> is charged via S<sub>3</sub> to the battery voltage plus the voltage across C<sub>3</sub>, that is, twice the battery voltage.

## Circuit description

The circuit diagram is shown in Fig. 3. As in Fig. 2, C<sub>1</sub> is the output capacitor and C<sub>3</sub> is the pump. The manufacturer recommends that, to ensure that the capacitors can be charged rapidly, they are of a type with low internal impedance. Schottky diode D<sub>1</sub> ensures that im-

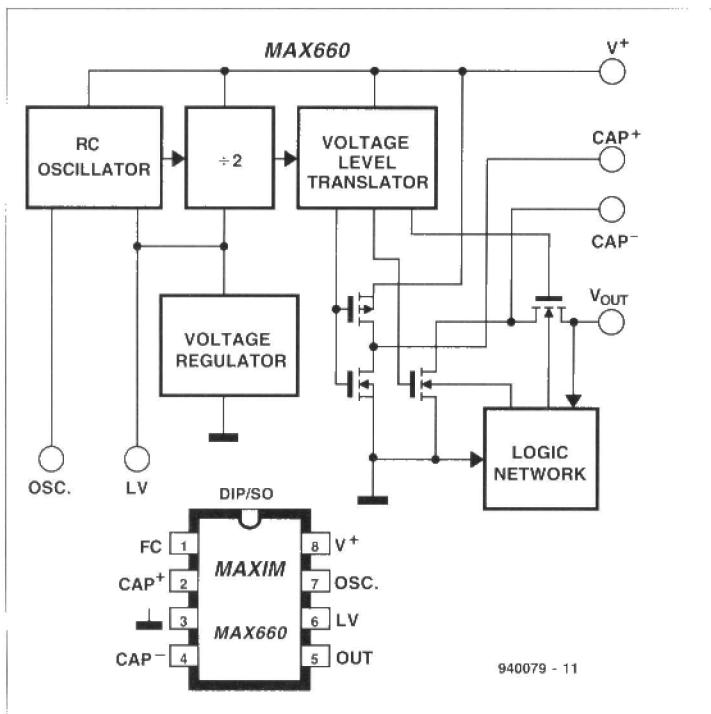


Fig. 1. Block diagram of the converter.

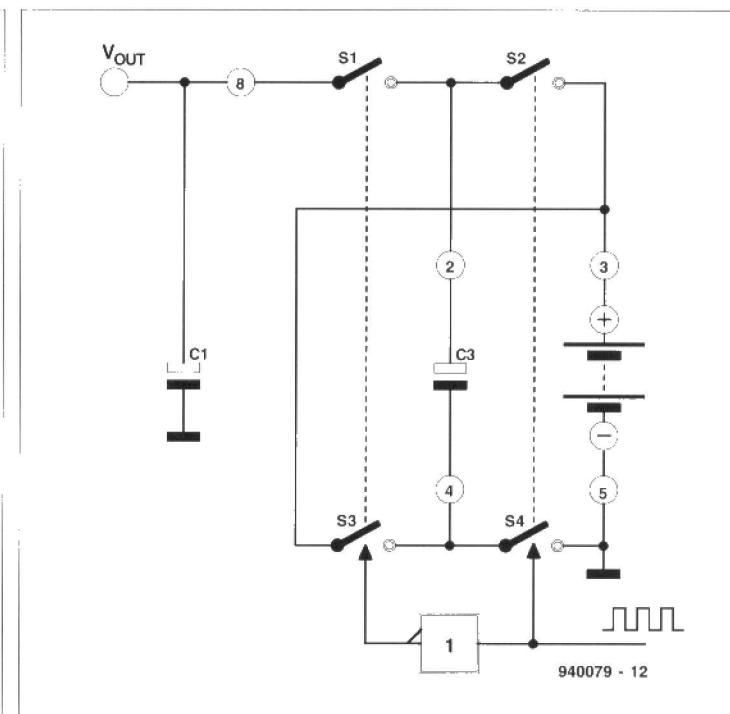
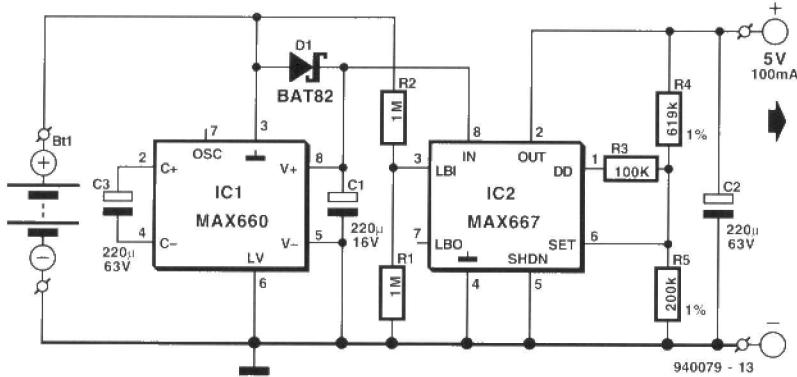


Fig. 2. Illustrating the action of the pump.



mediately after switch-on  $C_1$  gets charged to almost the full battery voltage.

The doubled battery voltage is applied to the input (pin 8) of IC<sub>2</sub>. This IC, which has a case identical to that of IC<sub>1</sub>, can best be described as low-power, low-drop 5 V voltage regulator. It can handle currents of up to 250 mA and drops only 150 mV at a current of 200 mA. At a current of 100 mA, as in the present converter, the voltage drop is about 100 mV.

The level of the output voltage,  $U_0$ , can be set very accurately with potential divider R<sub>4</sub>-R<sub>5</sub>. Since the internal reference potential,  $U_{\text{ref}}$ , of the IC is 1.255 V (which is available at pin 6).

$$U_0 = (R_4 + R_5) / R_5 \times U_{\text{ref}} \quad [\text{V}]$$

The MAX667 has a low-battery input (pin 3). The potential at this pin is compared with  $U_{\text{ref}}$ . If it is lower than the reference, the low battery output (pin 7) goes low and this level may be used to control an indicator, for instance, an LED. If pin 7 is con-

nected to a 10 kΩ pull-up resistor, its level may be used to drive a suitable CMOS circuit.

The input to pin 3 is derived from the battery via potential divider R<sub>1</sub>-R<sub>2</sub>. Since the divider ratio is 1:1, a low battery indication will be given when the battery voltage drops below 2.51 V (that is,  $2 \times U_{\text{ref}}$ ). If the low battery option is not needed, R<sub>1</sub> and R<sub>2</sub> may simply be omitted.

Resistor R<sub>3</sub> ensures that the output voltage is cut off when the drop across IC<sub>2</sub> becomes too low for good regulation.

## Construction

The converter may be built on the printed-circuit board shown in Fig. 4 (which is not available ready made) or on a piece of prototyping board.

Once the board has been finished, it is merely a matter of connecting the input voltage and checking with a multimeter that the output voltage is 5 V. It is advisable to recheck the output voltage with a 100 Ω resistor con-

nected in parallel with the meter.

Although it is unlikely that the converter will not work properly, it is advisable to check first whether the regulator or the voltage doubler is at fault. To this end, measure the voltage across C<sub>1</sub>; if this is equal to twice the battery voltage, IC<sub>1</sub> functions correctly.

In theory, the converter works satisfactorily with input voltages between 2.51 V and 5.5 V. A battery voltage of 5.5 V means that a voltage of 11 V is applied to the regulator, so that this must 'lose' 6 V. At a current of 100 mA, this means a dissipation of 600 mW, which is about the maximum the MAX667 can handle. It is thus advisable not to use such high battery voltages. In any case, is it sensible to double a battery voltage of 5.5 V and then regulate it down to 5 V?

## Parts list

### Resistors:

R<sub>1</sub>, R<sub>2</sub> = 1 MΩ

R<sub>3</sub> = 100 kΩ

R<sub>4</sub> = 619 kΩ, 1%

R<sub>5</sub> = 200 kΩ, 1%

### Capacitors:

C<sub>1</sub> = 220 μF, 16 V

C<sub>2</sub>, C<sub>3</sub> = 220 μF, 63 V

### Semiconductors:

D<sub>1</sub> = BAT82

### Integrated circuits:

IC<sub>1</sub> = MAX660 (CPA or EPA)

IC<sub>2</sub> = MAX667 (CPA or EPA)

[940079]

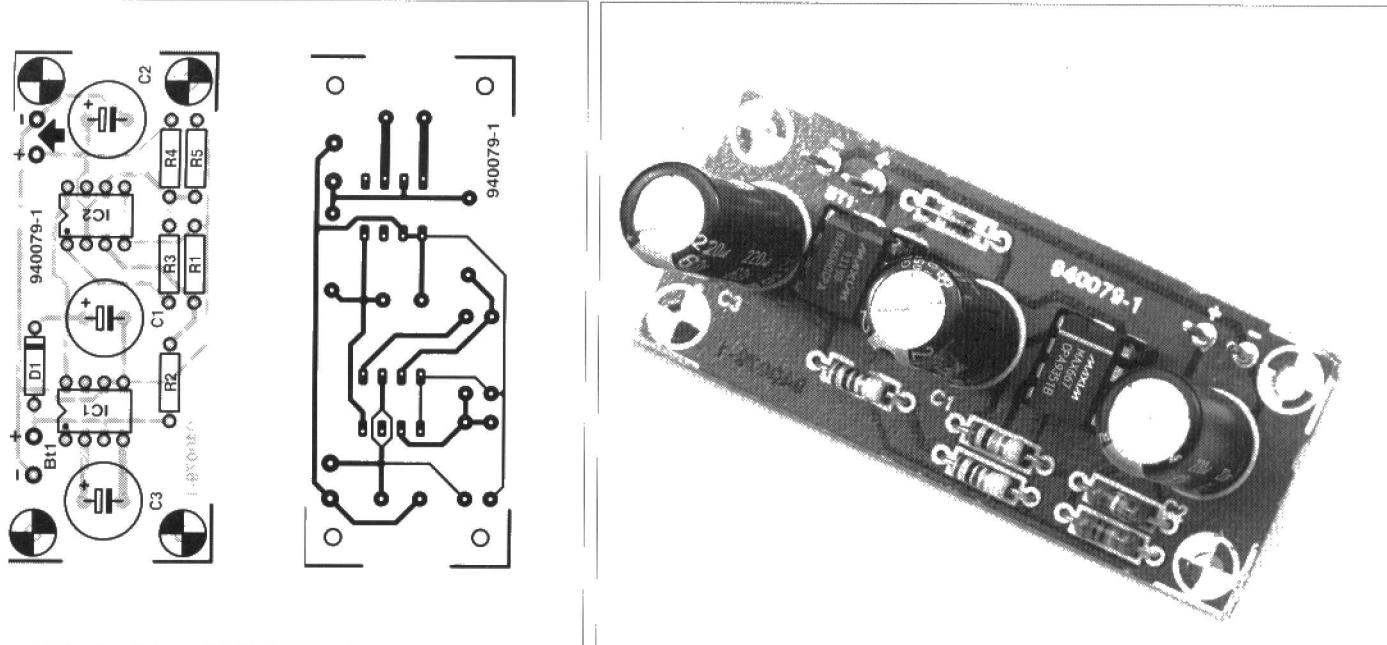


Fig. 4. Printed circuit board of the converter; at the right, the completed prototype.

# APPLICATION NOTE

The content of this note is based on information received from manufacturers in the electrical and electronics industries, or their representatives, and does not imply practical experience by Elektor Electronics or its consultants.

## VOICE SCRAMBLERS FX118 AND PCD4440

By G. Kleine

Owing to the vast increase in the number of mobile telephones, there is an equally vast demand (and need) for means of making listening to third-party telephone conversations impossible, or at least difficult. Two such means are introduced here; both are compact and require only low power. One is based on the Type FX118 IC from Consumer Microcircuits Ltd (CML) in England and the other is the PCD4440 from Philips of Holland, which is programmable via an I<sup>2</sup>C bus.

Both ICs use the principle of frequency inversion. In this, the frequency band of 300–3000 (or 3500) Hz is inverted so that low frequencies become high and vice versa. Where the FX118 provides a simple inversion of the band, the PCD4440 is more sophisticated. This IC splits the speech band into two at a programmed frequency and then inverts both parts independently. Since the programmed frequency can have any one of nine values, this chip offers good protection against eavesdroppers. Even higher protection is possible if the programmed frequencies in the trans-

	FX118	PCD4440
Function	Speech-band scrambler	Split frequency speech band scrambler
Number of speech channels	Scrambler and descrambler	Scrambler or descrambler
Power supply	3–5.5 V (typ. 3.75 V)	2.8–6.0 V (typ. 5.0 V)
Current drain	4 mA (typ.)	Typ. 13 mA (muted: 2.2 mA)
Input impedance	10 MΩ (typ.)	Typ. 120 kΩ
Output impedance	200 Ω (typ.)	<1 kΩ
Frequency range	300–3000 Hz	300–3500 Hz
Transfer gain	0.5 dB (opamp gain = 0 dB)	0 dB (transparent mode: -3.5 dB)
Spurious signal attenuation	≥40 dB	≥40 dB
Programmable	No	Via I <sup>2</sup> C bus
Clock	internal 4.433619 (same crystal as colour TV receiver)	External, 3.579 MHz
Packaging	FX118DW: 16 pin SOIC FX118P: 16 pin DIL	8 pin SOIC

Table 1. Main parameters of FX118 and PCD4440 ICs.

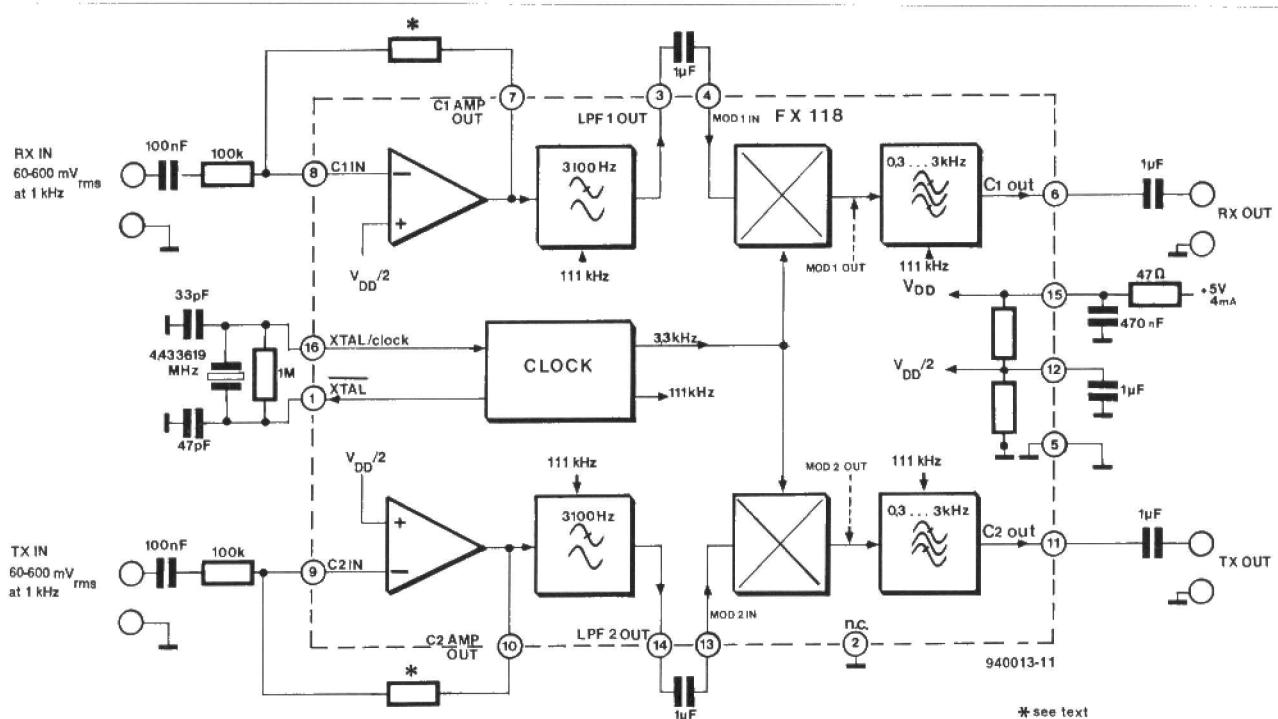


Fig. 1. Combined block and circuit diagram of the Type FX118 circuit.

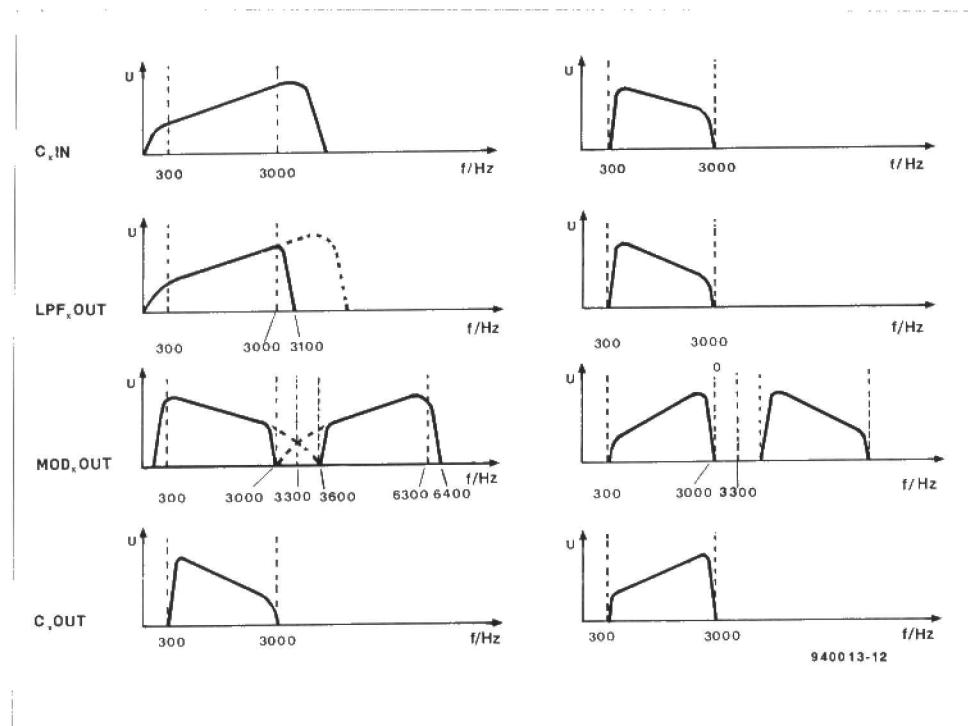


Fig. 2. Mode of operation of the FX118 (x: 1 for channel 1, 2 for channel 2).

mitter and receiver are synchronized. The programmed frequency can be changed ten times per second via the I<sup>2</sup>C bus.

The filters in both circuits are switched-capacitor (SC) types, that are aligned simply by the application of the correct clock signal to the relevant pin on the circuit. Some parameters of both circuits are given in **Table 1**.

## Frequency inverter FX118

A combined block and circuit diagram of du-

plex frequency inverter Type FX118 is given in **Fig. 1**. The circuit has two identical signal paths for scrambling and descrambling. The central clock, controlled by a 4.431619 MHz crystal, provides all internally required clock frequencies. The crystal has been chosen since it is the same as the inexpensive, easily obtainable one used in colour PAL TV receivers.

There is an amplifier in both signal paths, whose gain can be set by an external resistor. This enables the scrambler to work with

input signals of 60–600 mV r.m.s.

The input amplifier is followed by a 3100 Hz low-pass filter. The output of the filter is applied to a frequency changer, which mixes it with a signal of 3300 Hz. This results in a sum and difference frequency band. The difference signal band has the desired inversion and is filtered out by a 300–3000 Hz band-pass filter.

The other signal path which, as already stated, is identical can be used simultaneously for descrambling. This is why the chip is called a duplex frequency inverter. One channel scrambles the outgoing signal, while the other channel descrambles the incoming signal. The mode of operation in scrambling is shown on the hand of the various signals in **Fig. 2a**. The speech signal applied to pin C<sub>x</sub>IN (C<sub>1</sub>IN or C<sub>2</sub>IN) covers a frequency band of 300 Hz to about 5000 Hz. A low-pass filter removes all frequencies above 3100 Hz (LPF<sub>x</sub> OUT). The resulting signal is mixed with a signal of 3300 Hz (MOD<sub>x</sub> OUT), whereupon the original band is shifted to above 3300 Hz (sum signal). There is also a mirrored signal below 3300 Hz (difference signal), which has the desired frequency inversion. Because of the choice of 3300 Hz for the mixer frequency, the difference signal lies exactly in the band 300–3000 Hz. The following band-pass filter filters the 300–3000 Hz band from the output signal of the mixer (the sum signal is then eliminated) – C<sub>x</sub>OUT.

**Figure 2b** shows how the descrambling of the scrambled signal is carried out.

**Figure 3** shows the practical set-up of a radio telephone. Since each FX118 IC provides two signal paths (for scrambling and descrambling respectively), only one chip is required in the base station and one in the handheld unit: full duplex operation.

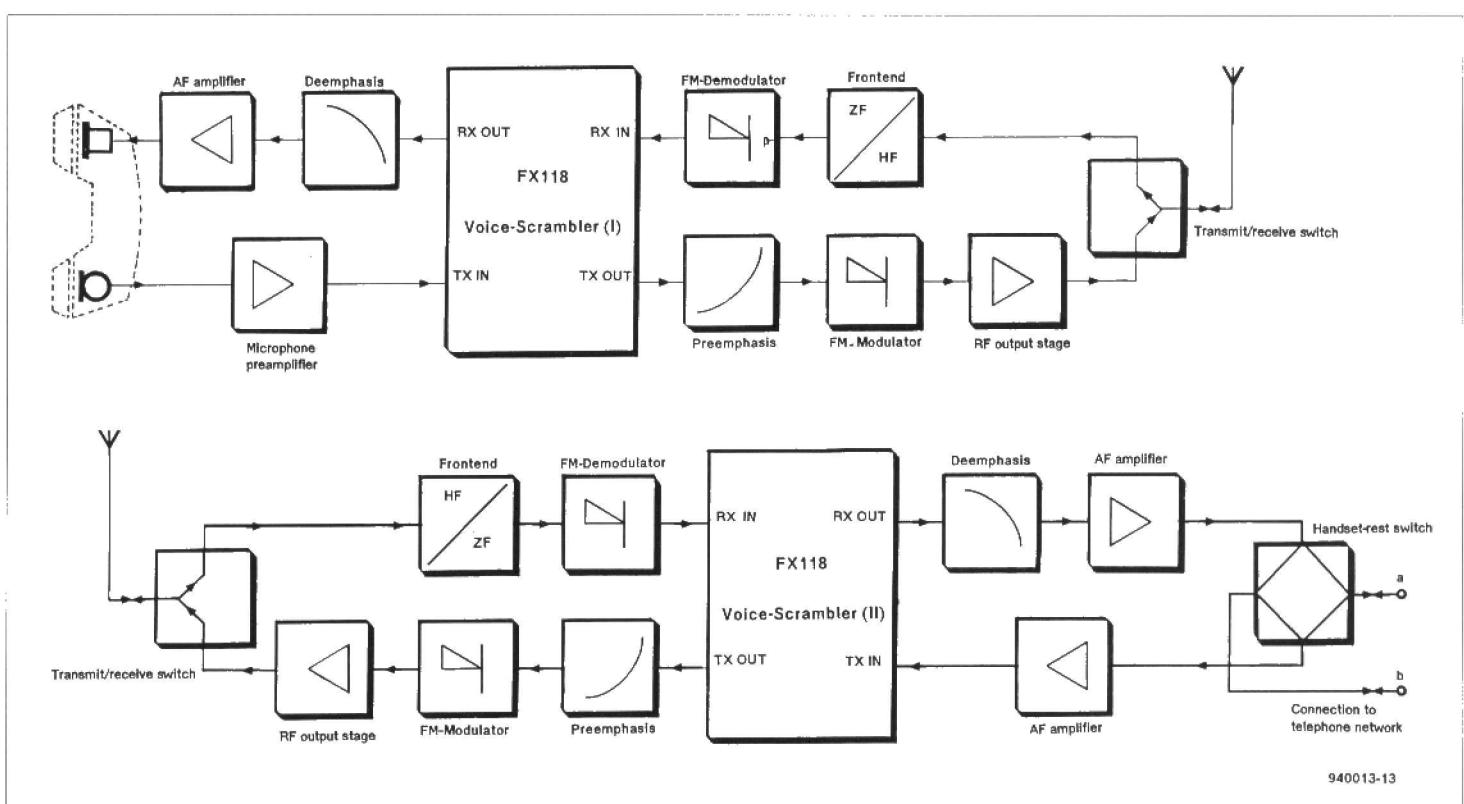


Fig. 3. Typical application of the Type FX118 circuit.

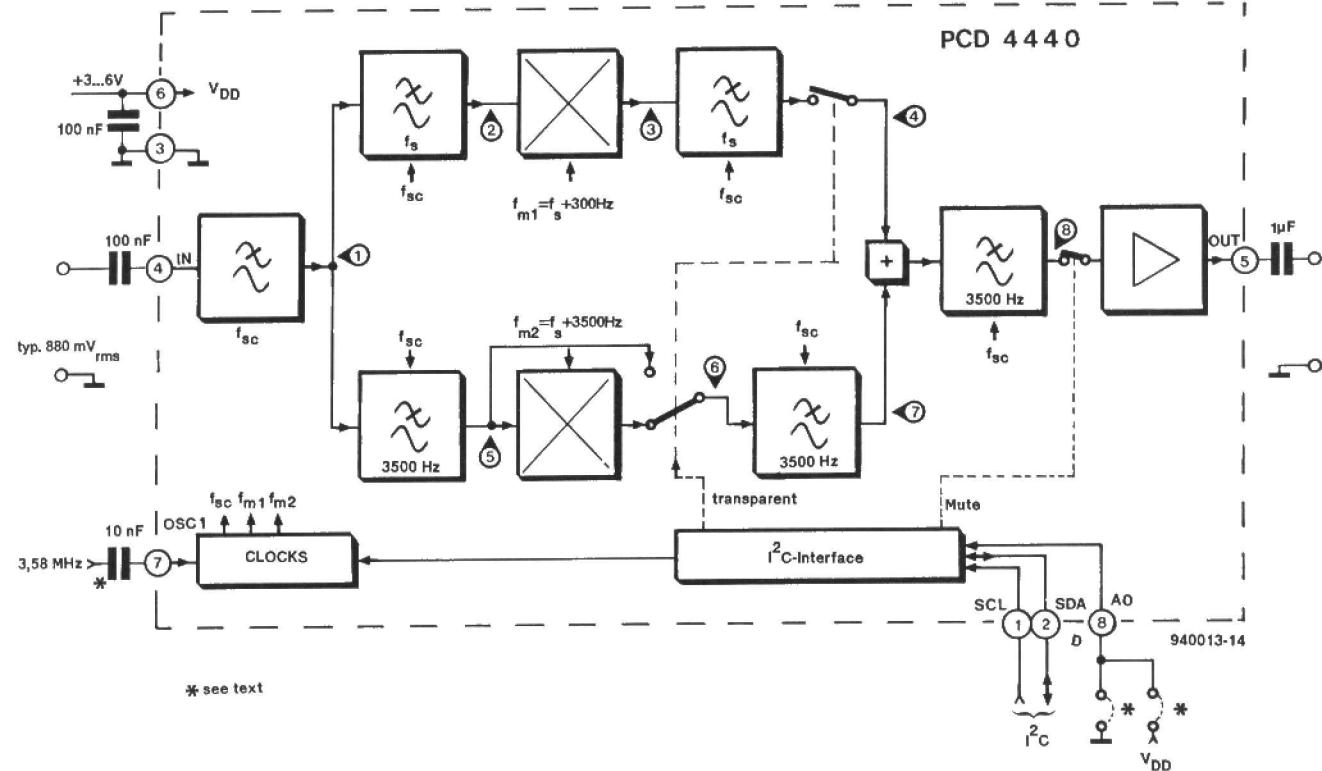


Fig. 4. Combined block and circuit diagram of the Type PCD4440 voice scrambler.

Communication is over two channels and uses frequency modulation. Noise suppression is effected by preemphasis at the transmitter and deemphasis at the receiver. High frequencies are amplified in the preemphasis network and attenuated again by the deemphasis network. Since in FM demodulation the signal-to-noise ratio deteriorates with higher modulation frequencies, the preemphasis and deemphasis networks ensure a level ratio.

### Voice scrambler PCD4440

The PCD4440 chip, whose block and circuit diagram is shown in Fig. 4, provides only one audio channel. It uses split-frequency operation, in which the speech frequency band is split at a programmable frequency,  $f_s$ , after which the two parts are inverted separately. This does, of course, give a higher degree of protection than attainable with the FX118. If then  $f_s$  is changed a number of times per second, it becomes virtually impossible to eavesdrop on the communication. Programming of one of up to nine possible frequencies,  $f_s$ , takes place via an I<sup>2</sup>C bus. The chip also has the facilities to pass the speech band transparently, that is, without scrambling and to mute the output. For duplex operation, two PCD4440 chips are needed in both the receiver and the transmitter.

The input (Fig. 5 ①) is applied to a low-pass filter, whose output is split over two signal paths. The upper path in Fig. 4 processes the frequency band below  $f_s$ . This band is filtered out by a low-pass section whose cut-off frequency is  $f_s$ . This range of signals (Fig. 5 ②) is applied to a frequency changer

where it is mixed with a signal,  $f_{m1} (=f_s+300\text{ Hz})$  (Fig. 5 ③). The resulting (inverted) signal (Fig. 5 ④) is passed through a further low-pass filter to ensure that any residual spurious signals are eliminated.

The upper part of the speech band is applied to a low-pass filter in the lower signal path in Fig. 4, which has a cut-off frequency of 3500 Hz (Fig. 5 ⑤). Thereupon it is applied to a frequency changer where it is mixed

with a signal,  $f_{m2} (=f_s+3500\text{ Hz})$  (Fig. 5 ⑥). The resulting signal is passed through a low-pass section which has a cut-off frequency of 3500 Hz (Fig. 5 ⑦).

The two (inverted) signals (Fig. 5 ⑧) are then applied to yet another low-pass filter (cut-off frequency = 3500 Hz) and amplified.

In the transparent mode of operation, the upper signal path is disabled and the frequency changer in the lower path is by-

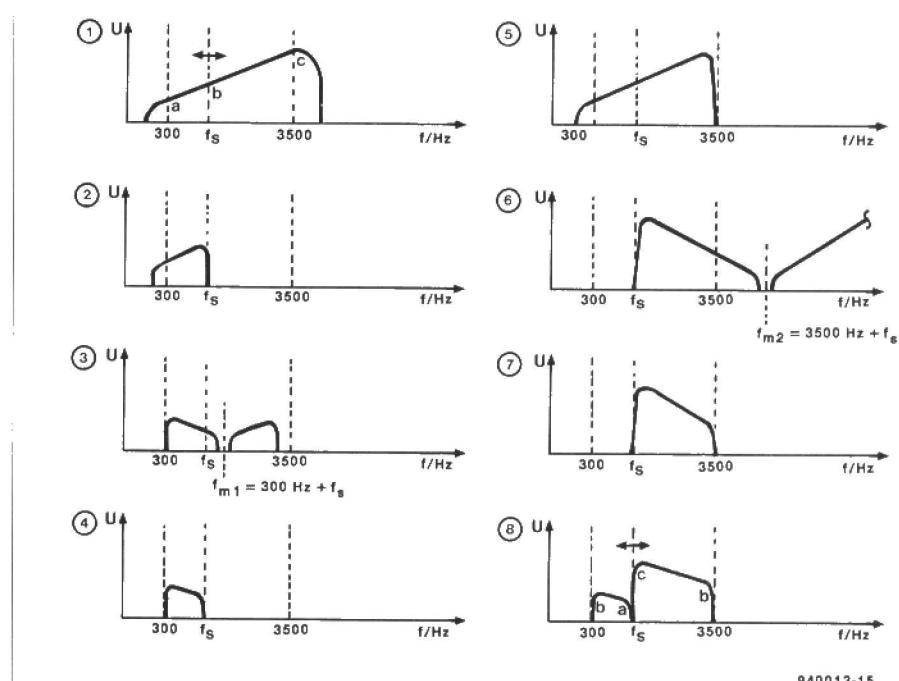


Fig. 5. Mode of operation of the PCD4440.

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## MINI I/O card for Casio FX850/880P

The 'Mini I/O card for the Casio FX850/880P', which was published in our March 1994 issue (page 50), needed a communication program, 'Casio FX850P Communication Utility Version 1.2'. This program was advertised as being available on a floppy disk, Ref. 1921. It was purchased by us as original work from a Mr G.J. Klasens, who signed the relevant Assignment of Copyright accordingly. However, on publication of the March issue, it transpired that the program had **not** been written by Mr. Klasens, but was the intellectual property of a Mr P.M.F. Paulissen. Mr. Klasens had merely added his name to the program and offered it as his own intellectual property.

Since software is an intellectual property which is protected by law in many countries (in UK: *Copyright, Designs and Patents Act 1988*, Section 56), a legal argument arose between Messrs Paulissen and Klasens, pending the outcome of which Elektor Electronics (Publishing) could not offer the program for sale.

The argument has now been resolved and we can advise readers that the program is available again under Ref. No. 1921. Readers who have a copy of the original floppy disk containing the now illegal version of the program are asked to return this to our Dorchester Office, whereupon they will be sent the new version of the program.

passed. This ensures that the input signal appears in unchanged form at the output. It is, however, passed through two low-pass

sections which remove any residual signals above 3500 Hz.

In muted operation, the output signal is switched off.

The PCD4440 is programmed as follows. **Figure 6** shows two signals, SCL and SDA, which represent the I<sup>2</sup>C bus. SCL is a clock line that is driven continuously by the I<sup>2</sup>C transmitter. SDA is the directional data line that is driven by the transmitter or the receiver. In principle, both I<sup>2</sup>C parties can pull these lines to ground to obviate any short-circuits caused by simultaneous drives. As shown in **Fig. 7**, both lines must be connected to the +5 V supply via external pull-up resistors.

**Figure 7** also shows how the PCD4440 is clocked. There is no facility to clock the PCD4440 via an independent crystal. It can, of course, be clocked by an independent, external quartz crystal oscillator.

The control via the I<sup>2</sup>C bus is always by an address followed by one or more data words. Receipt of each of these words is confirmed by the receiver

via an acknowledge pulse. This indicates that the PCD4440 has pulled the SDA line low while the controller generates the SCL clock pulse. Each I<sup>2</sup>C communication is begun with a start state and ends with a stop state.

The start state (SDA goes low before SCL) is followed by the address of the PCD4440. Depending on the level at pin 8, this is 1101110 ( $A_0 = 0$ ) or 1101111 ( $A_0 = 1$ ). These addresses are individually allocated to the PCD4440, so that the chip can be combined with other ICs that are controlled via I<sup>2</sup>C.

The R/W (read/write) bit that follows the address is set to write (R/W = 0).

The acknowledge pulse is followed by a single data word. This data word contains four bits, D<sub>3</sub>-D<sub>0</sub>, which set the split frequency,  $f_s$ , as well as the special modes—see **Table 2**. After  $f_s$  has been programmed, the PCD4440 must be enabled by the start instruction (0F hex).

## Summary

Both the FX118 and the PCD4440 circuits enable protection circuits to be designed for mobile telephones or other speech communication systems. Because of the use of switched capacitor (SC) filters, such circuits can be kept very compact; they need no alignment.

[940013]

Function	$f_s$ (Hz)	D <sub>3</sub>	D <sub>2</sub>	D <sub>1</sub>	D <sub>0</sub>
Mute		0	0	0	1
2461	0	0	1	0	
1853	0	0	1	1	
1507	0	1	0	0	
1279	0	1	0	1	
1117	0	1	1	0	
1018	0	1	1	1	
899	1	0	0	0	
837	1	0	0	1	
767	1	0	1	0	
Transparent	1	0	1	1	
Start descramble/ scramble mode	1	1	1	1	

Table 2. Programming of the PCD4440.

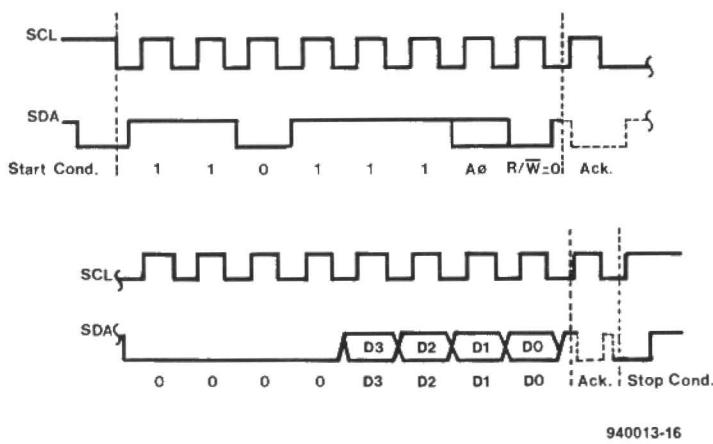


Fig. 6. I<sup>2</sup>C control of the PCD4440.

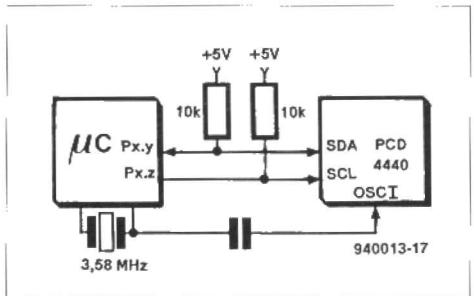


Fig. 7. Linking the PCD4440 to a microcontroller

# IN-CAR AUDIO AMPLIFIER - PART 1

Design by T. Giesberts

**The in-car audio amplifier is intended for public-minded drivers who not only love their in-car music, but also their hearing (and that of others), which is why they keep the volume of the car's audio system at reasonable volume levels – particularly when the car's windows are open. It is a sad fact that there are some unthinking drivers who do not realise that by having the volume fully up (or nearly so) they are destroying their hearing in a fairly short time (and at the same time, they are a public nuisance). By leaving the volume of your car's audio system at reasonable levels, you will be able to go on listening to your favourite in-car music long after the unthinking few have realised – sadly, too late – that all they can hear is a rushing in their ears – no more.**

The aspect of an in-car audio amplifier that makes it so expensive is not the amplifier itself, but the power supply. In domestic or industrial amplifiers, it is possible to obtain any supply voltage we wish from the mains. In a car, however, there is only a 12 V battery and that puts severe limits on the amplifier's power requirements. Roughly, the output power of an amplifier,  $P$ , is  $P = U_{pp}^2/8R_L$ , where  $U_{pp}$  is the peak-to-peak supply voltage and  $R_L$  is the loudspeaker impedance. Even with 4 Ω loudspeakers and a battery voltage of 13.8 V, the peak power is just about 6 W. A bridge amplifier might increase this to about 20 W. Lowering the load impedance to 2 Ω by shunting loudspeakers, can double this figure to 40 W, but that is all. The only way of obtaining output powers of 100–200 W into 4 Ω is increasing the on-board voltage by a suitable d.c.-d.c. converter, which is the solution chosen for the present amplifier. The amplifier proper will be described this month and the converter next month.

## Design considerations

The design of an in-car amplifier is rather different from that of a domestic power amplifier. This is because in the latter the major requirement is the best possible sound quality, which, to most hi-fi enthusiasts means very low distortion, high signal-to-noise ratio and a high slew-rate. In an in-car power amplifier, the main requirements are reliability, solidity, electrical and thermal stability, compactness, and, of course, good sound quality.

Other differences in the design of an in-car amplifier compared with that of a domestic amplifier are sensors for

protection against a short-circuit of the output, too high temperatures and direct voltages at the output. Because of the inevitable high ambient temperatures in a car, the cooling of the heat sink mounted output transistors is ensured by an electric fan. Moreover, the output transistors are of a type that can withstand very low loads – down to 1 Ω. Nevertheless, the over-current protection circuit comes into operation at full drive when the load drops below 3 Ω.

## Circuit description

Basically, the amplifier consists of a

voltage amplifying section,  $T_1-T_{10}$ , and a current amplifying section,  $T_{11}-T_{18}$  (see Fig. 2). The section around  $T_{19}-T_{22}$  forms part of the protection circuits.

The signal from the (existing) car radio is applied to the amplifier via  $C_1$ . This capacitor is the only one in the signal path and it is, therefore, a good-quality (polypropylene) type. From  $C_1$ , the signal passes through a low-pass filter,  $R_2-C_2$ , which limits the bandwidth of the signal to a reasonable, practical value.

The input amplifier is a differential one formed by  $T_{1a}$  and  $T_{1b}$ . The type of transistor used, a MAT02, ensures optimum symmetry and minimal drift. The bandwidth is further limited by  $R_8-C_3$ .  $R_{10}-C_4$  is a feedback network.

Zener diodes  $D_1$  and  $D_2$  protect  $T_1$  against too high a collector-emitter potential and thus to a needlessly large dissipation.

The d.c. setting of the differential amplifier is provided by current source  $T_2$ . To ensure the highest possible stability, reference diode  $D_4$  is thermally coupled to  $T_2$ . The current through the diode is held steady by current source  $T_3$ . It is important that the drop across  $D_4$  is exactly 1.8 V, since this ensures the correct level of current through  $T_1$ , and thus the voltage drop (3.3 V) across  $R_6$  and  $R_7$ . If the drop across  $D_4$  is not exactly 1.8 V, the d.c. setting can

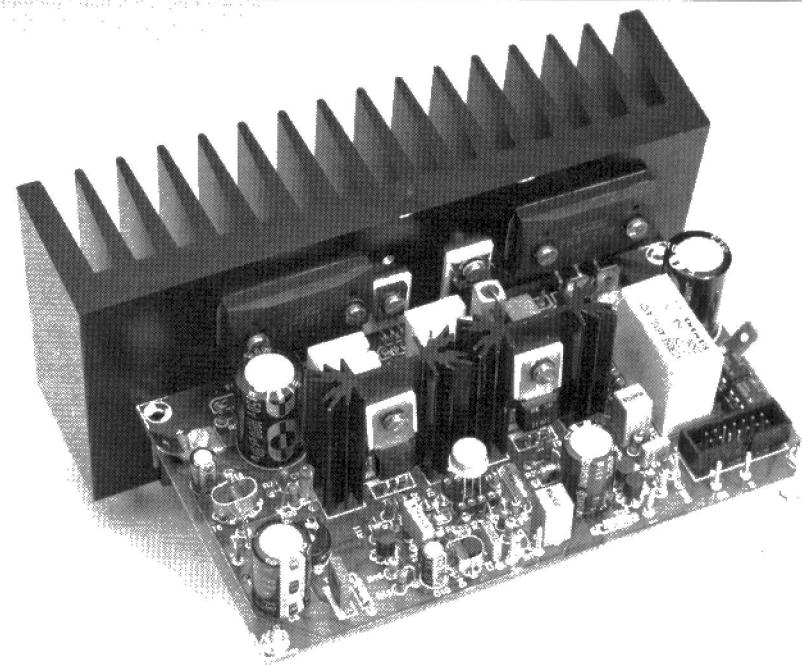
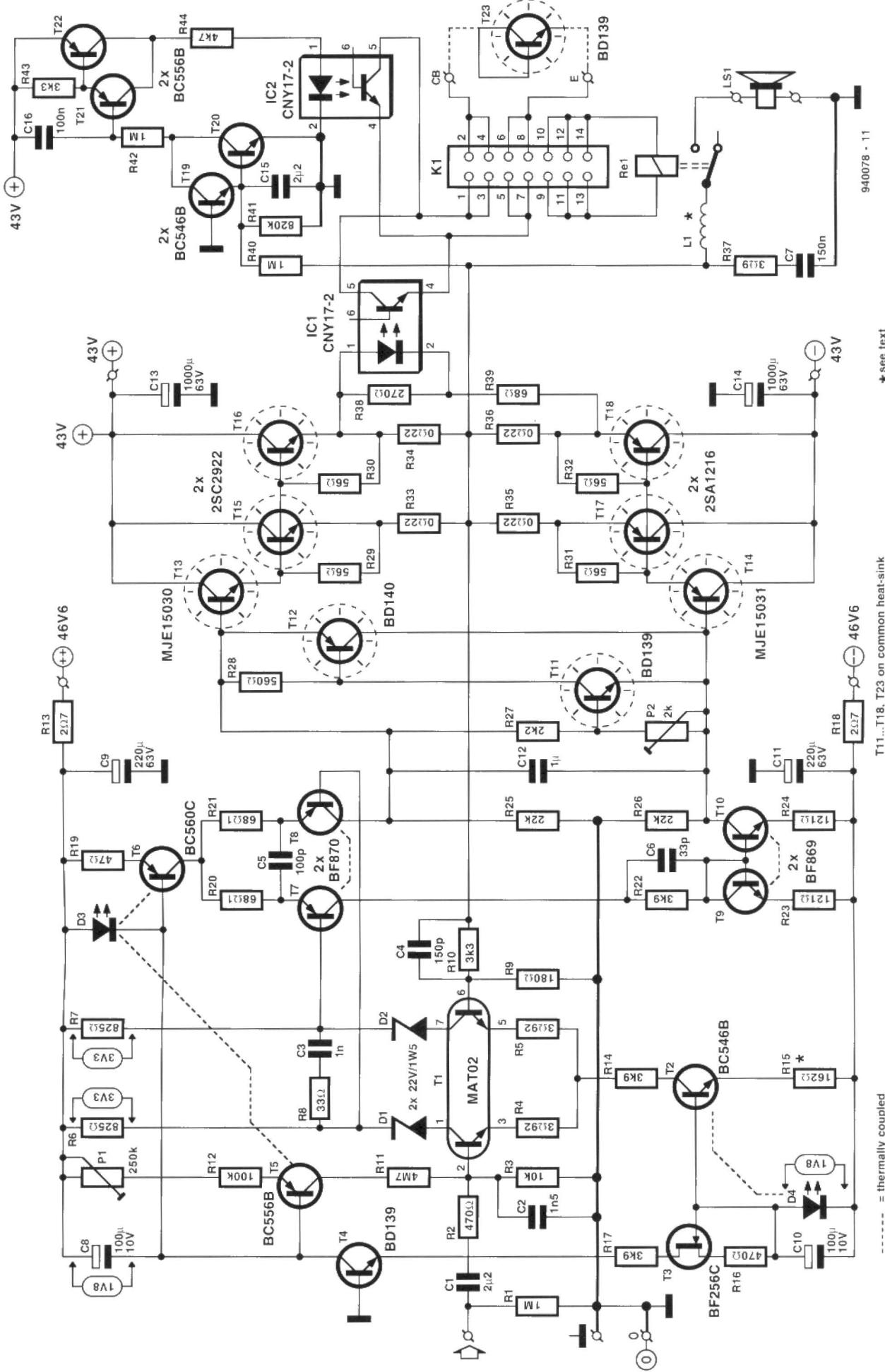


Fig. 1. Completed (mono) prototype amplifier (fan not shown).



**Fig. 2.** Circuit diagram of the in-car audio amplifier.

be corrected by (empirically) altering the value of  $R_{15}$  slightly.

Current source  $T_3$  also holds the voltage across  $D_3$  constant at 1.8 V. This diode serves as reference for current source  $T_5$  and is also part of another current source,  $T_6$ . It is, therefore, thermally coupled to both transistors.

Current source  $T_5$  ensures that the bias current for  $T_1$  is held at a steady level. It also provides, with  $R_{12}$  and  $P_1$ , a d.c. offset control.

Current source  $T_6$  provides the d.c. operating point of differential amplifier  $T_7-T_8$ . This amplifier is augmented by current mirror  $T_9-T_{10}$  to ensure a symmetrical drive to the current amplifier. Capacitor  $C_5$  provides frequency correction.

The current amplifier consists of two complementary emitter followers,  $T_{13}$  and  $T_{14}$ , and parallel-connected power stages  $T_{15}-T_{16}$  (n-p-n) and  $T_{17}-T_{18}$  (p-n-p). Variable 'zener diode'  $T_{11}-T_{12}$  provides precise control of the voltage across  $T_{13}-T_{18}$  and  $R_{33}-R_{36}$ . This voltage determines the quiescent current through the power transistors. Transistors  $T_{11}-T_{18}$  are mounted on a common heat sink to ensure good thermal coupling, so that the quiescent current remains stable even with rising temperature.

The level of the quiescent current (100 mA per transistor) enables the amplifier to process small signals in Class A (0.3 W into  $4\ \Omega$ ).

Capacitors  $C_{13}$  and  $C_{14}$  ensure sufficient spare current during short signal peaks.

Boucherot network  $R_{37}-C_7$  at the output ensures that the amplifier is loaded even at very high frequencies.

Inductor  $L_1$  limits current peaks that ensue with highly capacitive output loads.

## Protection

The supply to the amplifier consists of two different symmetrical voltages:  $\pm 43$  V for the current amplifier and  $\pm 46.6$  V for the voltage

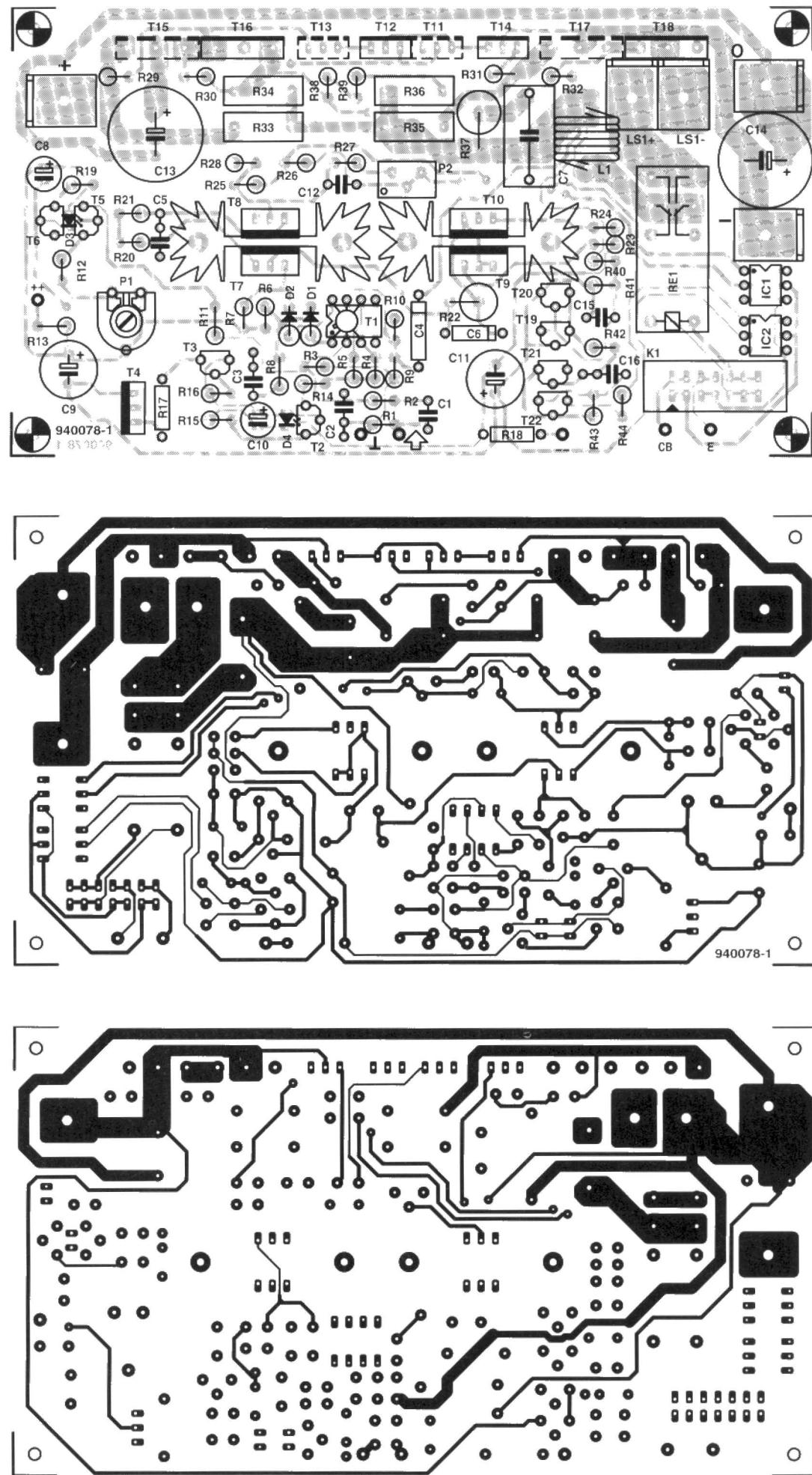
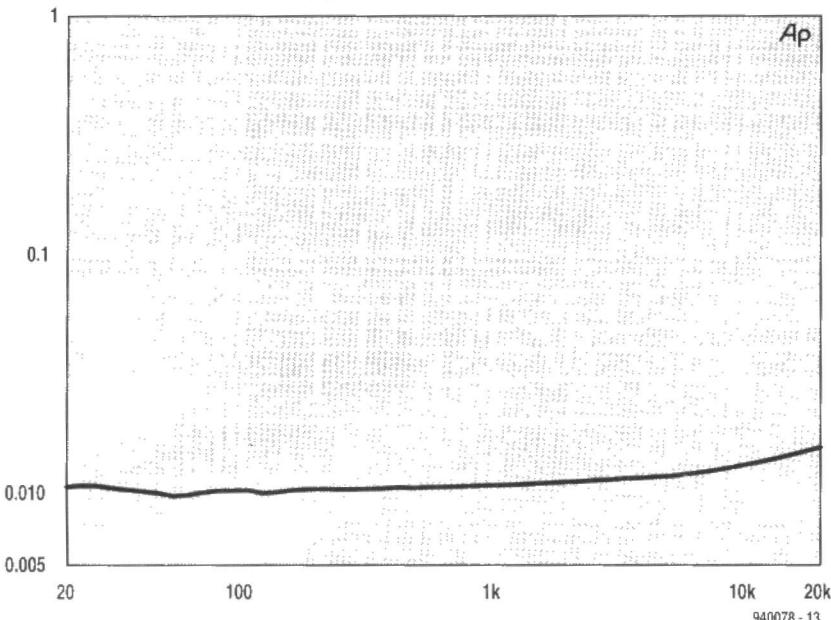


Fig. 3. Printed circuit board for the in-car audio amplifier (2 needed for stereo version).

AUDIO PRECISION DEFAULT THD+N(%) vs FREQ(Hz)

31 MAY 94 12:44:03

**Fig. 4.** Harmonic distortion vs frequency characteristic.

amplifier. The slightly higher supply to the voltage amplifier compensates for the inevitable drops, so that the current amplifier can be driven to its maximum supply voltage.

The supply voltages are generated by the converter to be described, together with the complete protection circuits, in Part 2. The sensors for the protection circuits are, however, located on the amplifier board, and these will be briefly discussed here.

In parallel with the emitter resistors of T<sub>16</sub> and T<sub>17</sub> is a potential divider, R<sub>38</sub>-R<sub>39</sub>, which controls optoisolator IC<sub>1</sub>. When the amplifier is overdriven, or the load drops below 3 Ω, or the output is short-circuited, the output current rises above 13.5 A, whereupon

the drop across R<sub>38</sub> will cause the optoisolator to conduct.

The circuit based on T<sub>19</sub>-T<sub>20</sub> controls optoisolator IC<sub>2</sub>, which is coupled to the amplifier output via R<sub>40</sub>. When a direct voltage exceeding ±1 V appears on the amplifier output, the optoisolator will be switched on: by T<sub>20</sub> when the direct voltage is positive, and by T<sub>19</sub> when the direct voltage is negative.

Transistor T<sub>23</sub> is a temperature monitor.

The three sensor outputs are taken to the protection circuit via box header K<sub>1</sub>. When one of the three sensors is actuated, the associated protection circuit deenergizes relay R<sub>e1</sub>, which thereupon disconnects the loudspeaker from the amplifier output.

The protection circuits are electrically isolated from the amplifier to prevent the converter causing possible earth loops between them and the source (car radio).

## Construction

The amplifier is best built on the (double-sided) printed-circuit board in **Fig. 3**. Note that this board is for a mono version; for a stereo version two boards are needed.

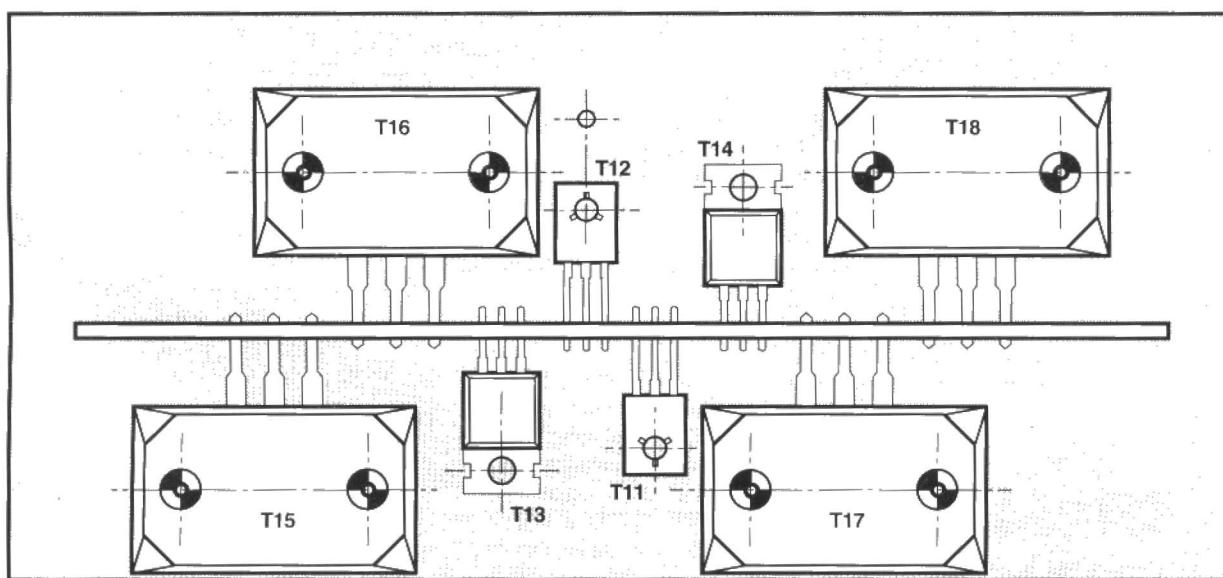
Most resistors must be mounted upright. Inductor L<sub>1</sub> is self-wound. Close-wind six turns of 1.5 mm diameter enamelled copper wire on an 8 mm dia. former (e.g., a pencil). Clean both ends for soldering and remove the former.

Diode D<sub>4</sub> and transistor T<sub>2</sub>, as well as transistors T<sub>5</sub>, T<sub>6</sub> and diode D<sub>3</sub> must be sandwiched together (flat side of the diodes against the transistor(s)). Clamp the combinations together with a strip of copper or tin plate to ensure good thermal coupling. Note that the LEDs must be types that drop exactly 1.8 V when the current through them is 5 mA (check this with a suitable supply and a series resistor).

The 43 V supply lines ('+', '0', '-'), as well as the loudspeaker leads, must be connected to the board(s) via heavy-duty car-type connectors (rated at 25–30 A). The 46.6 V lines ('+', '0', and '-') carry only small currents and can thus be soldered to standard solder pins.

The heat sink on which T<sub>7</sub>-T<sub>8</sub> and T<sub>9</sub>-T<sub>10</sub> are fixed (insulated with ceramic washers and heat transfer paste) must be soldered at right angles to the board(s) with the aid of solder pins (see **Fig. 1**).

Mount T<sub>11</sub>, T<sub>13</sub>, T<sub>15</sub>, and T<sub>17</sub> to the track side of the board and T<sub>12</sub>, T<sub>14</sub>, T<sub>16</sub>

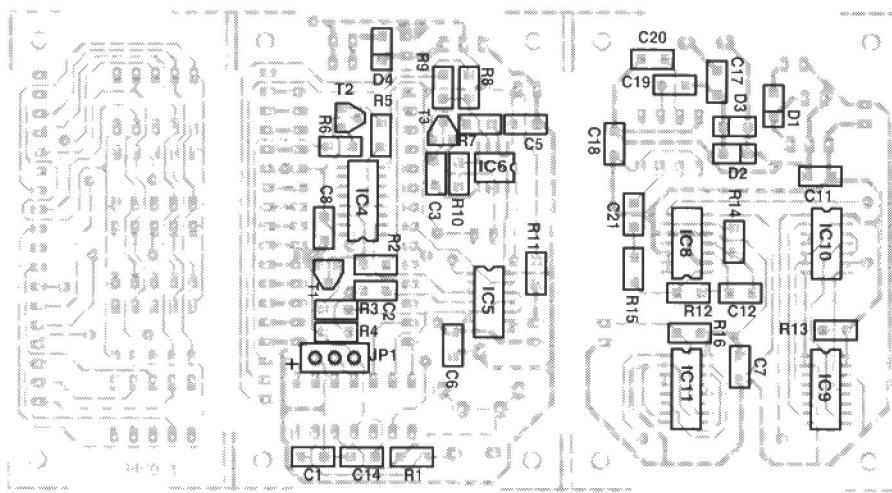


940078 - 12

**Fig. 5.** Template for drilling the heat sink; scale 1:1 (width = 160 mm)

The order forms are on page 71 this month.

## COMPACT FREQUENCY METER (SEPTEMBER 1994)



We apologise for the inconvenience caused to readers by the omission from our September 1994 issue of the third part of the double-sided through-plated printed-circuit board for the 'Compact frequency meter', which is now reproduced on the left.

and  $T_{18}$  to the component side. Then, attach the board at right angles to the relevant heat sink as shown in **Fig. 1** and **4**. **Figure 4** may also be used as template for drilling the necessary holes. All these transistors must be insulated from the heat sink with ceramic washers and heat transfer paste. It may be difficult or even impossible to obtain ceramic washers for  $T_{15}$ - $T_{18}$ ; if so, use mica washers. Note that the specified heat sink allows the amplifier to provide an output of not more than 120 W into  $4\ \Omega$  at an ambient temperature of  $30\text{ }^\circ\text{C}$  (which is not very high in a car in summer). The full power (200 W into  $4\ \Omega$ ) can only be realised when forced cooling is used.

### Parts list

#### Resistors:

$R_1, R_{40}, R_{42} = 1\text{ M}\Omega$   
 $R_2, R_{16} = 470\ \Omega$   
 $R_3 = 10\text{ k}\Omega$   
 $R_4, R_5 = 3.92\ \Omega, 1\%$   
 $R_6, R_7 = 825\ \Omega, 1\%$   
 $R_8 = 33\ \Omega$   
 $R_9 = 180\ \Omega$   
 $R_{10}, R_{43} = 3.3\text{ k}\Omega$   
 $R_{11} = 4.7\text{ M}\Omega$   
 $R_{12} = 100\text{ k}\Omega$   
 $R_{13}, R_{18} = 2.7\ \Omega$   
 $R_{14}, R_{17} = 3.9\text{ k}\Omega$

$R_{15} = 162\ \Omega, 1\% - \text{see text}$

$R_{19} = 47\ \Omega$

$R_{20}, R_{21} = 68.1\ \Omega, 1\%$

$R_{22} = 3.9\text{ k}\Omega, 1\text{ W}$

$R_{23}, R_{24} = 121\ \Omega, 1\%$

$R_{25}, R_{26} = 22\text{ k}\Omega$

$R_{27} = 2.2\text{ k}\Omega$

$R_{28} = 560\ \Omega$

$R_{29}-R_{32} = 56\ \Omega$

$R_{33}-R_{36} = 0.22\ \Omega, 5\text{ W}$ , low inductance

$R_{37} = 3.9\ \Omega, 5\text{ W}$

$R_{38} = 270\ \Omega$

$R_{39} = 68\ \Omega$

$R_{41} = 820\text{ k}\Omega$

$R_{44} = 4.7\text{ k}\Omega$

$P_1 = 220\ (250)\text{ k}\Omega$  preset

$P_2 = 2\text{ k}\Omega$  multturn preset, vertical

#### Capacitors:

$C_1, C_{15} = 2.2\ \mu\text{F}$ , polypropylene, pitch 5 mm  
 $C_2 = 1.5\text{ nF}$   
 $C_3 = 1\text{ nF}$   
 $C_4 = 150\text{ pF}$ , 160 V, polystyrene  
 $C_5 = 100\text{ pF}$ , 160 V, polystyrene  
 $C_6 = 33\text{ pF}$ , 160 V, polystyrene  
 $C_7 = 150\text{ nF}$ , 160 V, polypropylene  
 $C_8, C_{10} = 100\ \mu\text{F}$ , 10 V, radial  
 $C_9, C_{11} = 220\ \mu\text{F}$ , 63 V, radial  
 $C_{12} = 1\ \mu\text{F}$ , polypropylene, pitch 5 mm  
 $C_{13}, C_{14} = 1000\ \mu\text{F}$ , 63 V, radial  
 $C_{16} = 100\text{ nF}$

#### Semiconductors:

$D_1, D_2 = \text{zener, } 22\text{ V, } 1.5\text{ W}$

$D_3, D_4 = \text{LED, flat, } (U_{\text{drop}} = 1.8\text{ V})$

$T_1 = \text{MAT02}$

$T_2, T_{19}, T_{20} = \text{BC546B}$

$T_3 = \text{BF256C}$

$T_4, T_{11}, T_{23} = \text{BD139}$

$T_5, T_{21}, T_{22} = \text{BC556B}$

$T_6 = \text{BC560C}$

$T_7, T_8 = \text{BF870 (BF872)}$

$T_9, T_{10} = \text{BF869 (BF871)}$

$T_{12} = \text{BD140}$

$T_{13} = \text{MJE15030}$

$T_{14} = \text{MJE15031}$

$T_{15}, T_{16} = \text{2SC2922}$

$T_{17}, T_{18} = \text{2SA1216}$

#### Integrated circuits:

$\text{IC}_1, \text{IC}_2 = \text{CNY17-2}$

#### Miscellaneous:

$L_1 = \text{see text for winding instructions}$

$K_1 = 14\text{-way straight box header}$

$\text{Re}_1 = 12\text{ V, car type relay with two change-over contacts rated at } 16\text{ A}$   
 $\text{Five car-type heavy-duty plug/socket sets(plugs to be screw on type for PCB fitting)}$

$\text{Two off heat sink } 11\text{ K W}^{-1} (38.1\text{ mm})$   
 $\text{for } T_7-T_8 \text{ and } T_9-T_{10}$

$\text{Heat sink } 0.5\text{ K W}^{-1} (\text{see text})$

$\text{Two off } 12\text{ V, } 230\text{ mA fan (Canon CF80-T211N1D or similar)}$

[940078-I]

# ELECTRONIC KNOW-HOW

## Transformers – an overview

By K. Schönhoff

The development of transformers is closely connected with the history of alternating voltage. It was the Danish physicist Hans Christian Oersted who discovered in 1820 that a current-carrying conductor produces a magnetic field. Ten years later, the American physicist Josef Henry discovered electromagnetic induction, the 'conversion of magnetism into electricity'. In late 1831, Michael Faraday conducted a series of experiments with a device that consisted of an iron toroid around which two windings of insulated copper wire had been placed (see Fig. 1). He connected a battery to one of the windings and hoped that a direct voltage would be induced in the other winding. But to his surprise, even after two hundred experiments, the only time the galvanometer across winding B deflected was when he connected or disconnected the battery from winding A. It was only after the French instrument maker, Pixii, in 1832, built a hand-operated alternating voltage generator (alternator) that the transformer could be further researched and developed.

Early researchers, who applied alternating voltage across an inductance, and measured the consequent voltage and current, discovered that the electrical resistance of a coil changes when an iron rod was inserted into it. This resistance increased further when the iron was formed into a closed circuit. The kind of iron also had an effect on the resistance; this was greatest with soft iron (i.e. iron low in carbon, which is unable to retain magnetism). If a second winding was placed over the iron, but insulated from the first winding, it was found that if an alternating voltage was applied across the first winding, an alternating voltage was induced in the second winding. The secondary voltage was found to be high when the winding consisted of many turns.

### Transformer core

The iron core improves the transformer action in two respects. Firstly, it increases the electrical resistance of the winding to an applied alternating voltage. The current in an air-cored coil to which an alternating voltage is applied increases about four times as

fast as in an iron-cored coil. Secondly, the iron contains many small magnets which are normally so distributed that their actions cancel one another. They are, however, mobile and can be placed in such a position by an external field that they magnify this field. This magnified field produces a much greater self inductance.

### Eddy currents

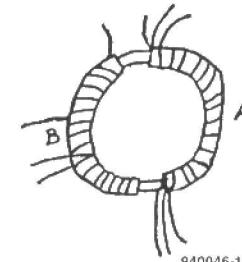
The iron core of a transformer is an electrical conductor. The outer periphery of the core forms a closed loop and acts thus just like a turn of the winding. This means that a voltage is induced across it and a current flows through it. The core consists of many such closed loops in which small currents, so-called Eddy current, flow. These currents cause power dissipation (loss), which is noticeable by the warming of the transformer during operation.

This power loss is minimized by making the core not of solid iron, but of thin wafers of steel, laminations, which are electrically insulated from one another. Moreover, the electrical resistance of the laminations is increased by the addition of a small amount of silicon to the steel.

The insulation between the laminations consists of a 6–10 µm thick, single-sided layer of varnish, a 2–3 µm thick double-sided coating of phosphate, or a 2–3 µm thick oxide coating.

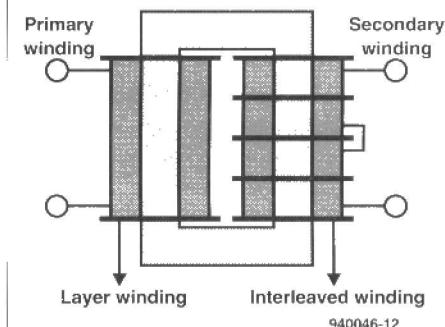
The space factor, that is, the ratio of the active cross-sectional area to the total area, varies from 0.75 (lamination thickness 0.05 mm) to 0.92 (lamination thickness 0.5 mm).

The diameter of some common



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Fig. 1



Primary winding

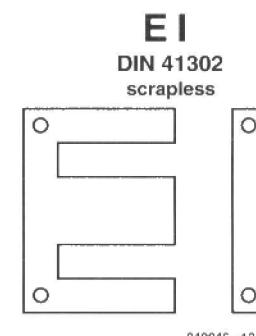
Secondary winding

Layer winding

Interleaved winding

940046-12

Fig. 2



EI  
DIN 41302  
scrapless

940046-13

Fig. 3

Insulation		Wire diameter in mm			
		0.1	0.5	1	5
enamel	single	0.011	0.028	0.040	0.060
	double	0.021	0.045	0.065	0.100
rayon	single	0.05	0.06	0.07	
	double	0.09	0.11	0.12	
cotton	single		0.10	0.12	
	double		0.16	0.22	0.40
paper	single		0.12	0.12	0.20
	double		0.22	0.22	0.35

Table 1. Diameter of some commonly encountered winding wire.

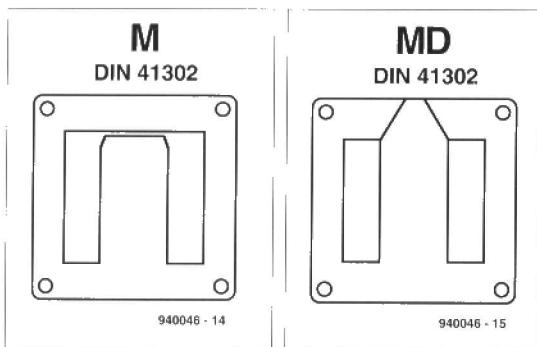


Fig. 4.

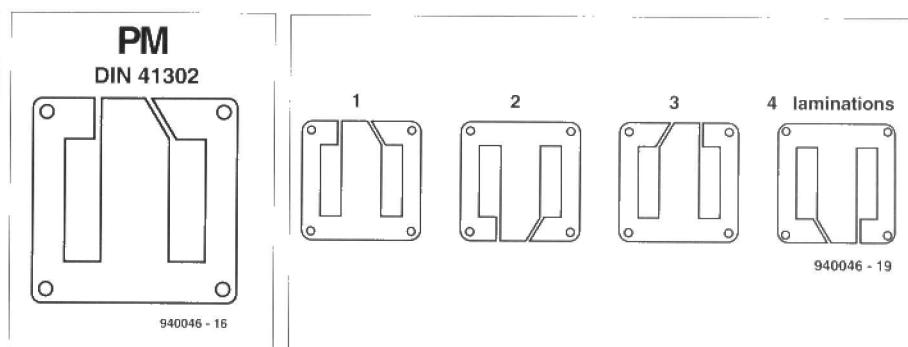


Fig. 5

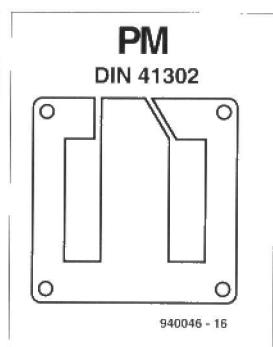


Fig. 6

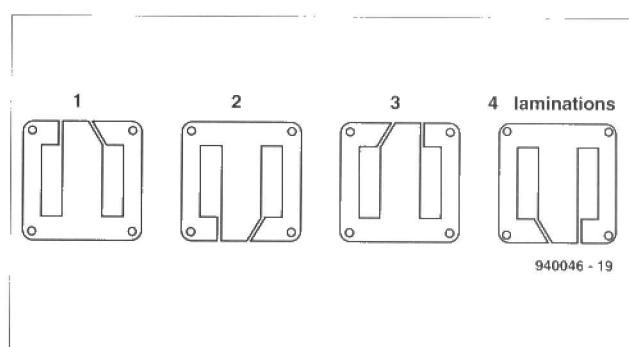


Fig. 7

winding wire is given in Table 1.

### Saturation

When the current through the primary winding increases, the field strength and the magnetization of the core also increase. However, at a certain level of current, the magnetization no longer increases: the core is saturated, but the (weak) field around the transformer becomes stronger. This stray field can cause interference in electronic circuits. Moreover, the energy transfer to the secondary winding deteriorates, because not all the lines of force produced by the primary embrace the secondary.

The stray field is particularly bother-

some when the primary and secondary are relatively far from each other, as on a UI core. It is not so strong when the windings are adjacent on the same limb of the core, and weaker still when the windings are on top of one another, as in most transformers.

Two properties of the core are particularly important for computing a transformer design: the degree to which it can be magnetized before saturation occurs and the permeability, that is, the degree to which it magnifies an external field. These factors determine the number of turns required for a certain voltage. The higher the magnetizability, the fewer turns are needed in both windings. The number of turns also depends on the cross-sectional

area of the core and the form factor of the transformer.

### Laminations

Originally, transformers were needed to provide relatively high power for energy supply systems. They used a rectangular core with well separated windings (see **Fig. 2**): this ensured good electrical isolation. The windings invariably consisted of cotton-insulated copper wire. In case of a failure, each of the windings could be removed and repaired or replaced.

When, later, transformers were needed for powering small equipment, their designs started to use so-called shell-type cores—see **Fig. 3**. Shell-type cores are sub-divided into EI, M and F types, according to their shape.

The EI type is particularly suitable for transformers that need a small air gap (down to 10 µm). The output voltage of such transformers is load-dependent, which is, for instance, useful in battery chargers that must deliver a constant current. This type of transformer is also useful in amplifiers. In a single-ended class A output stage flows

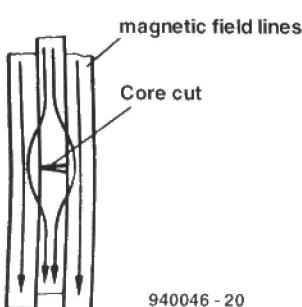


Fig. 8

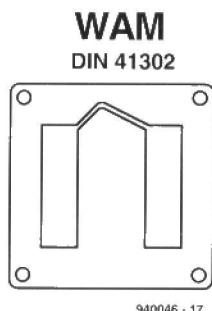


Fig. 9

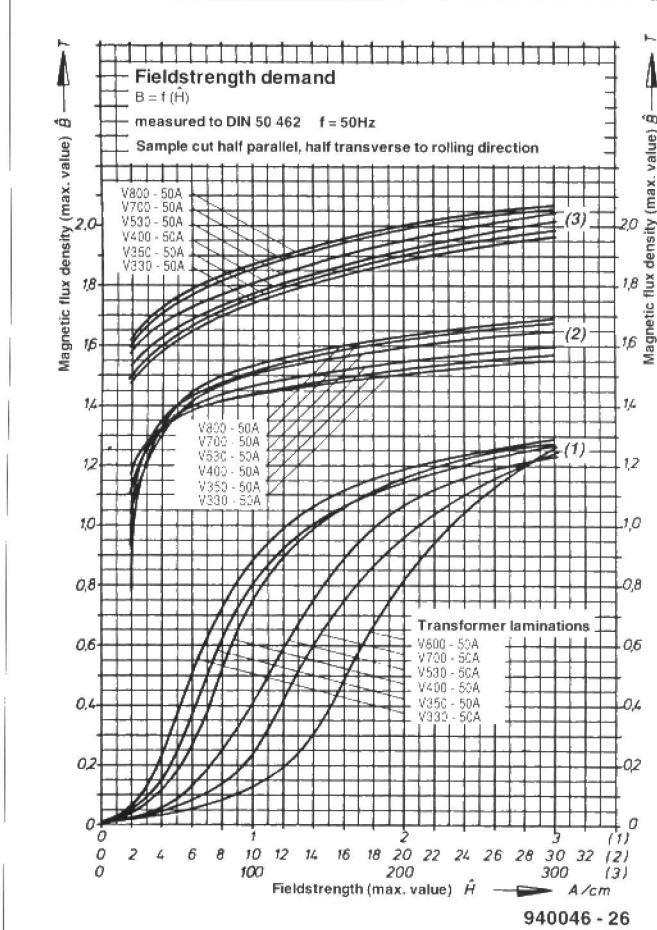


Fig. 10

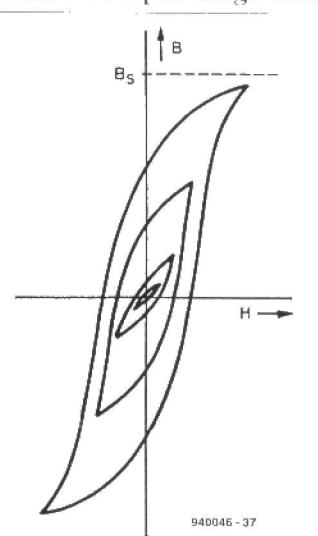


Fig. 11

**Table 2. Electrical data for transformers with M and EI cores (EI=scrapless).**  
**[Laminations Type V170-50A to DIN 41 302, Part 2 ( $\eta = 0.94$ )].**  
**These are but two of the many tables contained in transformer design books.**

Type & size	Secondary power cos $\varphi = 1$		Magnetic flux $B_H$	Current density $S_H$	Reactive power $P_B$	Iron losses $P_{Fe}$	Copper losses $P_{Cuw}$	Current factor $\Delta_i$	Voltage factor $\Delta_u$	Effective efficiency $\eta_W$	Apparent efficiency $\eta_S$	Power factor cos $\varphi$	Thermal resistance	
	W	T											For copper losses $R_{Hcu}$	For iron losses $R_{Hfe}$
M 42	3,94	1,37	6,7		4,31	0,68	3,81	1,365	1,76	0,467	0,416	0,89	22,6	10,8
M 55	15,8	1,38	4,97		11,6	1,78	5,7	1,267	1,301	0,68	0,61	0,89	14,1	6,4
M 65	34,1	1,39	4,1		21,5	3,25	7,6	1,228	1,188	0,76	0,69	0,9	10,2	4,45
M 74	62	1,39	3,51		34,5	5,2	9,3	1,198	1,13	0,81	0,74	0,91	7,9	3,35
M 85	a	82	1,37	3,47	43,2	6,9	10,4	1,189	1,111	0,83	0,76	0,92	6,8	2,8
	b	108	1,33	3,31	51	9,1	10,9	1,17	1,09	0,84	0,78	0,93	6,1	2,5
M 102	a	143	1,42	2,94	67	10,8	13,5	1,163	1,084	0,85	0,79	0,93	5	2,02
	b	198	1,31	2,76	79	14,6	14,1	1,139	1,065	0,87	0,82	0,94	4,45	1,75

Type & size	Secondary power cos $\varphi = 1$		Magnetic flux $B_H$	Current density $S_H$	Reactive power $P_B$	Iron losses $P_{Fe}$	Copper losses $P_{Cuw}$	Current factor $\Delta_i$	Voltage factor $\Delta_u$	Effective efficiency $\eta_W$	Apparent efficiency $\eta_S$	Power factor cos $\varphi$	Thermal resistance	
	W	T											For copper losses $R_{Hcu}$	For iron losses $R_{Hfe}$
M 42	4,05	1,38	6,8		4,53	0,51	3,91	1,348	1,76	0,478	0,421	0,88	22,6	10,8
M 55	16,4	1,4	5,1		12,7	1,36	6	1,262	1,301	0,69	0,61	0,88	14,1	6,4
M 65	35,7	1,42	4,21		24,4	2,5	8	1,231	1,188	0,77	0,68	0,88	10,2	4,45
M 74	65	1,43	3,62		40,8	4,06	9,9	1,208	1,129	0,82	0,73	0,89	7,9	3,35
M 85	a	87	1,41	3,6	53	5,5	11,2	1,204	1,109	0,84	0,75	0,89	6,8	2,8
	b	116	1,39	3,44	66	7,5	11,8	1,193	1,087	0,86	0,77	0,9	6,1	2,5
M 102	a	154	1,42	3,05	86	8,7	14,6	1,184	1,083	0,87	0,78	0,9	5	2,02
	b	215	1,39	2,87	111	12,4	15,2	1,169	1,062	0,89	0,81	0,91	4,45	1,75

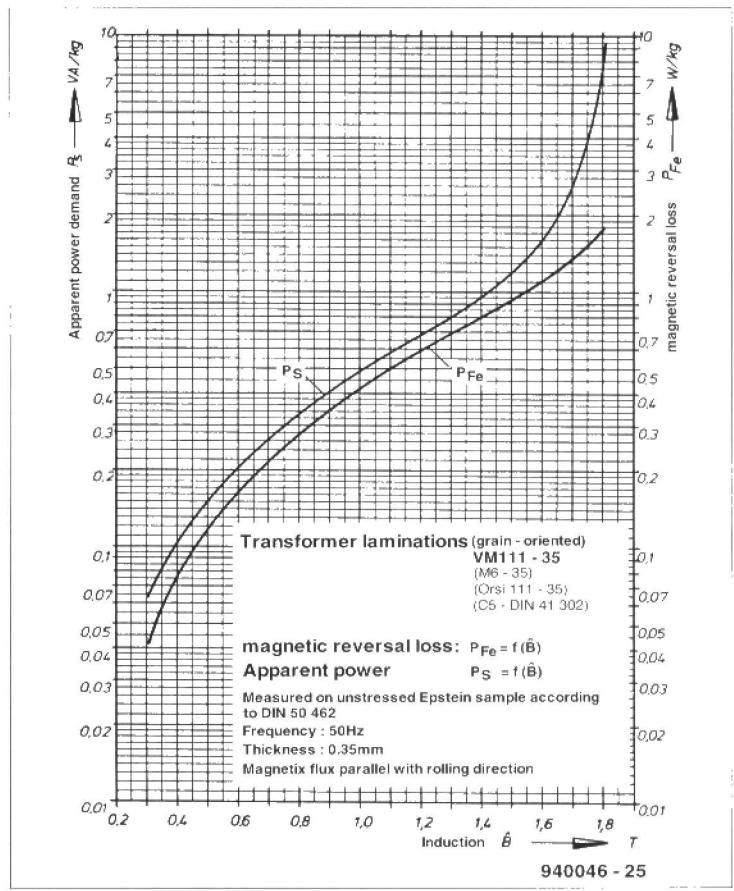
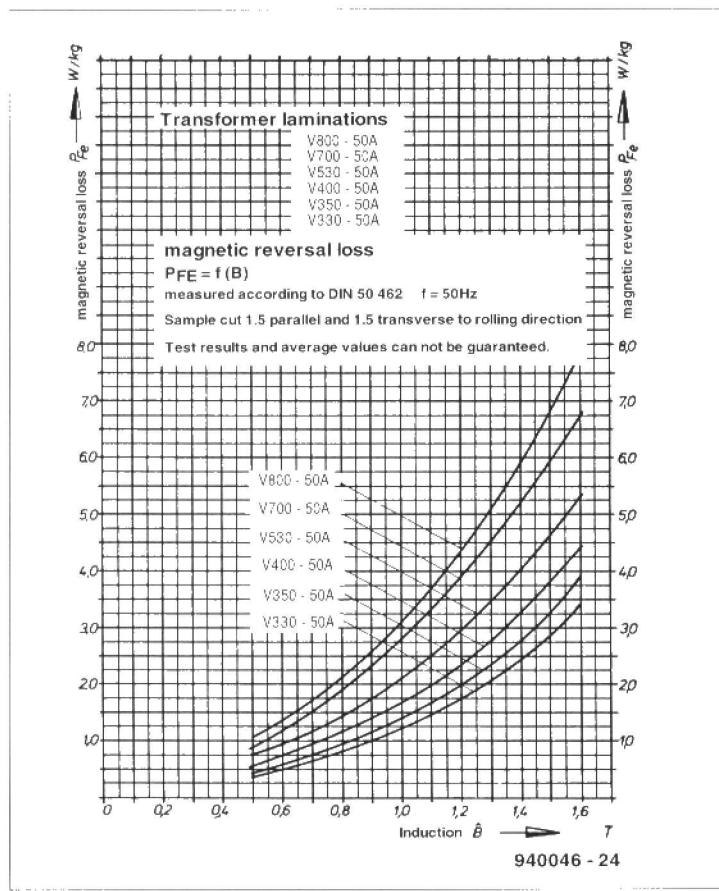


Fig. 12

Fig. 13

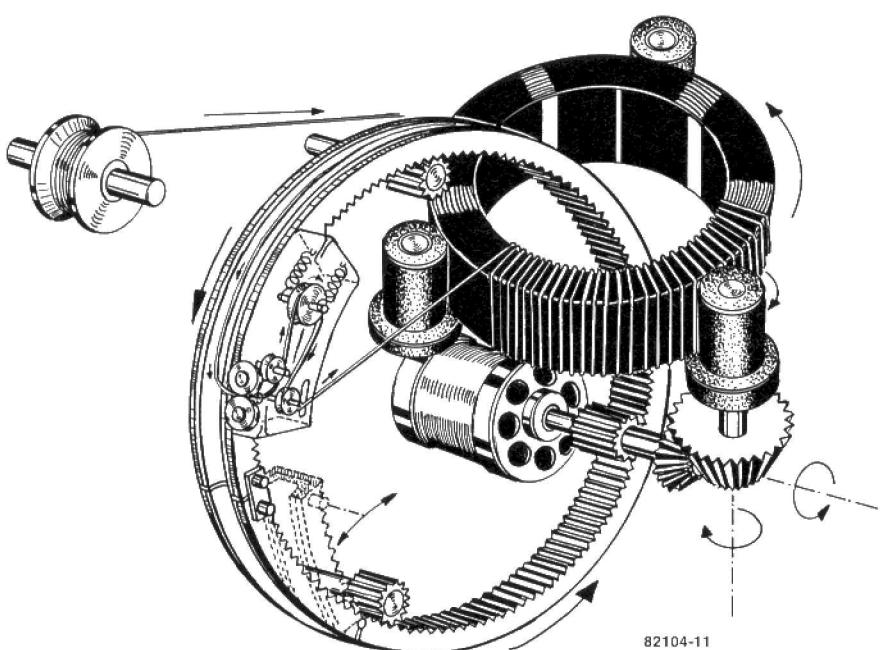


Fig. 14

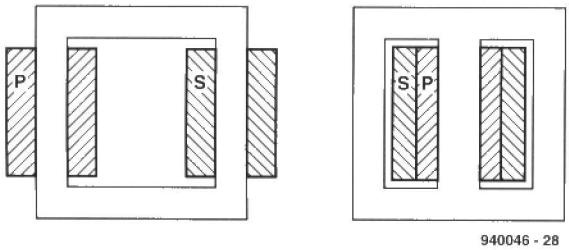


Fig. 15

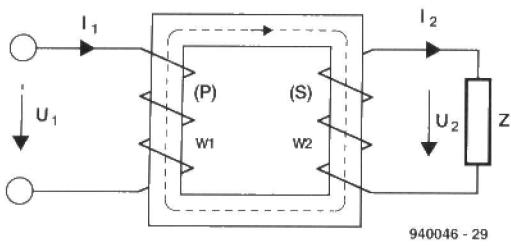


Fig. 16

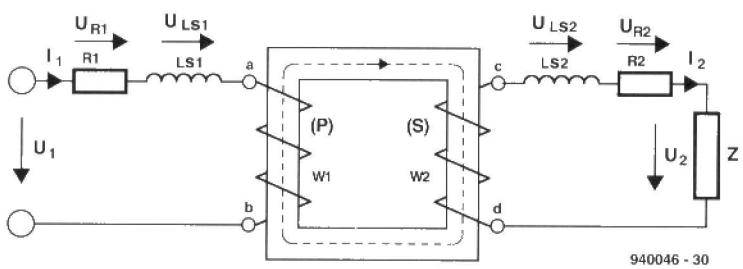


Fig. 17

not only alternating, but also direct current. The air gap prevents the direct current pre-magnetizing the core, which then may become saturated when the alternating current begins to flow or increases.

The M type cored transformer—see **Fig. 4**—is intended mainly for special applications, where its relatively strong stray field does not matter.

### Capacity improvement

Special alloys for the laminations coupled with particular rolling processes have improved magnetic properties considerably. In grain-oriented core materials, the grains are oriented by cold rolling of the material. They are aligned in the same direction as the magnetic flux established in the laminations. This improves the parallel, but not the transverse, magnetizability.

In the MD core—see **Fig. 5**—which made its appearance in the 1960s, the transverse magnetizability is also improved. In this core, the effect of the air gap is reduced by aligning the lamination joints in the direction of minimum flux density.

The PM core—see **Fig. 6**—is a further enhancement of the M type. Its improvements include a widening of the outer shell compared with the inner shell, which results in a weaker magnetization of the outer limbs than in the centre limb. Also, strengthening of the limbs results in a smaller magnetic resistance, so that the core can contain more lines of force, which reduces losses. Moreover, the arrangements of the laminations in layers of four—see **Fig. 7**—means that each air gap is flanked at either side by three closed loops (laminations) that act as diversion for the lines of force (see **Fig. 8**). These improvements mean an even better efficiency and weaker stray field than obtainable with the MD core.

A few years ago, the PM core was itself improved by a longitudinal shift of the winding window and optimization of the air gap to raise the efficiency by a further few per cent.

Apart from the standard types, there are several special types from a number of manufacturers, such as that in **Fig. 9**. The manufacturer states that this has the same good properties of the PM types, but the better physical stability of the M type.

### Computations

The basic transformer formula is

$$U_1 = 4.44 \times 10^{-4} \times B \times A_c \times f \times N_1,$$

where

$U_1$  = primary voltage in V;

$B$  = magnetic flux density in tesla;

$A_c$  = cross-sectional area of the core in

$\text{cm}^2$ ;  
 $f$  = mains frequency;  
 $N_1$  = number of primary turns.

Assume that a transformer, operating from a 240 V, 50 Hz mains supply is required to deliver a secondary voltage of 24 V. An M65 core (see Table 2) with a cross-sectional area of 4.9  $\text{cm}^2$ , which allows a maximum flux density of 1.42 T and a secondary power dissipation of 35.7 W, will be used. How many primary turns will be required?

Rearranging the formula and inserting the specified values gives

$$\begin{aligned} N_1 &= U_1 / (4.44 \times 10^{-4} \times B \times A_c \times f) \\ &= 240 / (4.44 \times 10^{-4} \times 1.42 \times 4.9 \times 50) \\ &= 1553 \text{ turns.} \end{aligned}$$

If the mains voltage were 250 V, the flux density would be

$$\begin{aligned} B &= U_1 / (4.44 \times 10^{-4} \times N_1 \times A_c \times f) \\ &= 1.48 \text{ T.} \end{aligned}$$

which exceeds the permissible maximum, so that the transformer would be driven into saturation. This shows that in these calculations the highest expected primary voltage must be taken into account, which includes mains variations ( $\pm 5\%$ ).

The effective efficiency is read from Table 2 as 77%. If grain-oriented M laminations VM 111-35 had been used, a core of the same dimensions would have allowed a dissipation of 43 W and given an effective efficiency of 81%.

Note in the formulas that  $B$  is inversely proportional to the frequency.

## Hysteresis

When the frequency of the primary voltage is increased greatly, the losses in the core become so large that laminations can no longer be used. They are replaced by compressed iron-dust cores in which the losses are much smaller. Also in wide use are ferrite cores, which consist of high-resistance magnetic material consisting principally of ferric oxide and one or more other metals. After being powdered and sintered, ferrites exhibit low eddy current losses at high frequencies and thus make ideal core material for RF inductors and switching elements. Other cores for use in RF transformers and inductors are made of ferromagnetic spinels, which are high permeable and resistive ceramic-like materials that exhibit very low eddy current losses and high permeability.

**Figure 10** shows typical magnetization curves for laminated cores. **Figure 11** shows typical hysteresis curves of laminated transformers.

Hysteresis is the tendency of a magnetic material to saturate and retain

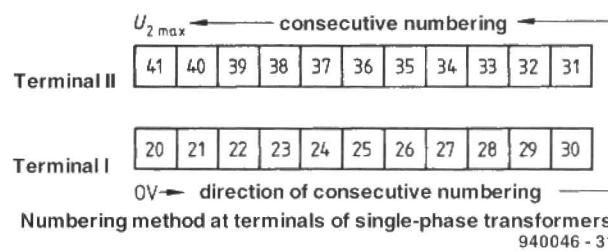


Fig. 18

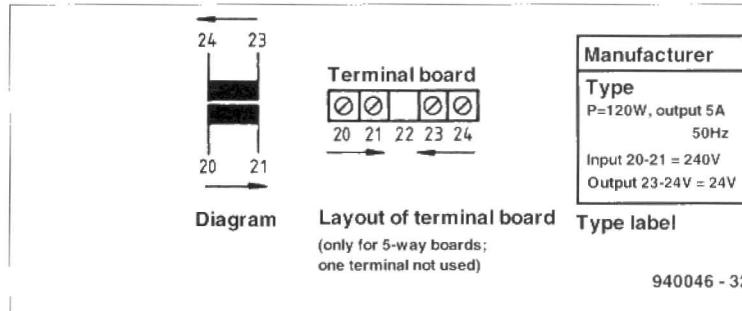


Fig. 19

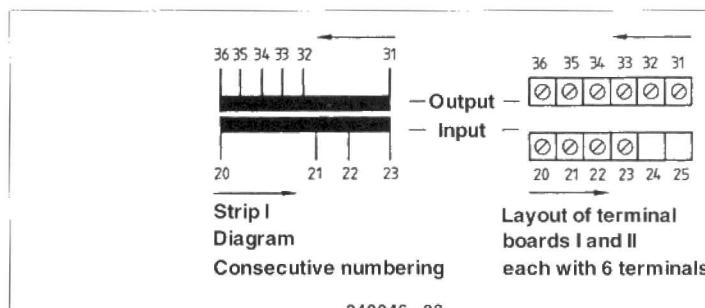


Fig. 20

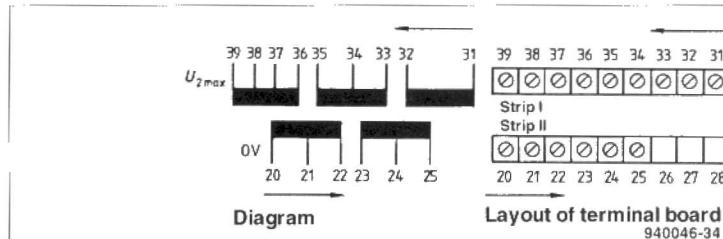


Fig. 21

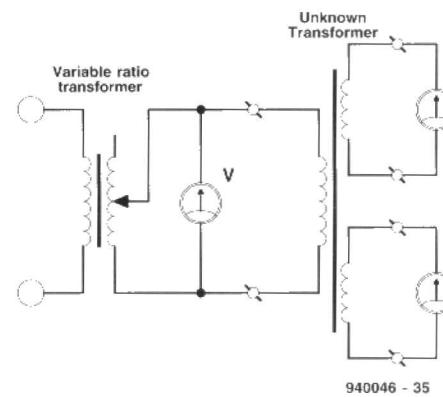


Fig. 22

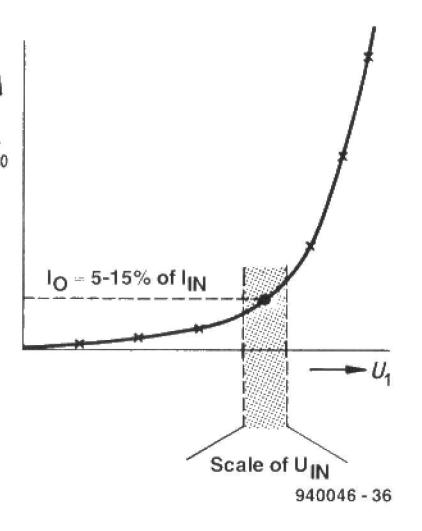


Fig. 23

some of its magnetism after the alternating magnetic field to which it is subjected reverses polarity, thus causing magnetization to lag behind the magnetizing force. The area of the hysteresis loop is a measure of the energy loss at each magnetic reversal. Figures 12 and 13 give energy loss characteristics for various kinds of lamination at 50 Hz. Hysteresis losses increase rapidly with rising frequency; at a few thousand hertz, only ferrites exhibit low hysteresis losses.

### Toroidal transformers

In toroidal transformers, the core consists of a single long foil of magnetic material that is turned into a toroid. The primary and secondary windings are placed on to this toroid by a special technique—see Fig. 14. In these transformers, all lines of force point in the same direction.

The thinner the strip of magnetic material is, the lower the losses in the iron. Therefore, these cores are normally made of very thin foil. It is hard to think of a better closed magnetic loop.

Although the core is entirely surrounded by the windings, so that it tends to get warm, this is offset by the fact that the windings easily radiate heat. In the design of toroidal transformers, this property is used by allowing the copper losses to increase by the use of thin wire. Therefore, the resistance of a toroidal transformer is larger than that of a laminated transformer with the same power handling. Physically, however, the toroidal transformer is smaller.

### Some theory

Basically, the operation of a transformer depends on mutual induction.

The primary and secondary windings lie in the same magnetic flux. The basic design of a transformer is shown in Fig. 15; its circuit diagram in Fig. 16.

An alternating current in the primary gives rise to an alternating flux within the core. If the current is sinusoidal and it is assumed that the flux is always directly proportional to the current, then

$$\phi = \phi_m \sin 2\pi ft$$

describes the variation with time of the flux.  $\phi$  is the flux at time  $t$ ,  $\phi_m$  is the maximum value of the flux and  $f$  the frequency with which the current, and thus the flux, alternates. The induced e.m.f. per turn is given by

$$\begin{aligned} U &= -(d\phi/dt) \\ &= -[d(\phi_m \sin 2\pi ft)/dt] \\ &= -2\pi f\phi_m \cos 2\pi ft. \end{aligned}$$

The maximum value of this induced e.m.f. per turn,  $U_m$ , occurs when the cosine term has its maximum value of 1. Thus,

$$U_m = 2\pi f\phi_m.$$

The r.m.s. value of this e.m.f.,  $U_{rms}$ , is given by

$$\begin{aligned} U_{rms} &= U_m / \sqrt{2} = 2\pi f\phi_m / \sqrt{2} \\ &= 4.44 f\phi_m. \end{aligned}$$

If the primary has  $N_1$  turns, the r.m.s. value of the primary e.m.f.,  $U_1$ , is  $4.44 N_1 f\phi_m$ . If the secondary has  $N_2$  turns, the r.m.s. value of the secondary e.m.f.,  $U_2$ , is  $4.44 N_2 f\phi_m$ .

The ratio  $U_1:U_2 = N_1:N_2 = n$  is the turns (or transformation) ratio of the transformer.

When a load is connected across the secondary, a current  $I_2$  flows through it which tends to counter the change in flux. This results in a lowering of the counter-e.m.f. in the primary, so that the primary current,  $I_1$ , rises. This rise exactly counters the demagnetizing effect of the secondary current.

So far, the resistance of the primary and secondary windings, as well as any stray fields, have been neglected. In practice, the primary causes a stray flux  $\phi_{s1}$ , which is not linked to the secondary. Similarly, the secondary generates a stray flux,  $\phi_{s2}$ , that is not linked to the primary. These fluxes induce voltages  $U_{s1}$  and  $U_{s2}$ , which lag the stray fluxes by  $\pi/2$ .

It may be assumed that, since these stray fluxes exist primarily in the air, they do not depend on the induction. The stray fluxes, and thus  $U_{s1}$  and  $U_{s2}$ , are directly proportional to  $I_1$  and  $I_2$ .

For our calculations, it does not matter whether the voltages are induced in the windings or in separate, air-cored coils. The inductances of these imaginary coils are determined by

$$j\omega L_{s1} = jX_{s1} = U_{s1}/I_1$$

and

$$j\omega L_{s2} = jX_{s2} = U_{s2}/I_2.$$

These coils and the resistance of the windings are shown in Fig. 17.

### Terminations

Terminations on 'unknown' transformers that are marked by one or two rows of figures between 20 and 99 are almost certainly to DIN 42200. These numbers contain useful information. Most good-quality transformers have two rows of figures: their numbering is as shown in Fig. 18:

Terminations rated up to 25 A max.

row 1: starting with 20 up to 60

row 2: starting with 31 up to 60

Terminations rated up to 60 A max.

row 1: starting with 61 up to 99

row 2: starting with 71 up to 99.

For the row with primary terminations the following applies: start with 0 V at termination 20 and then up with increasing potential. See Fig. 19-21.

For the row with secondary terminations: start with the highest output voltage at the highest numbered termination and then down with decreasing potential. See Fig. 19-21.

The open-circuit voltage of an unknown transformer may be determined with a set-up as in Fig. 22. Up to saturation of the transformer, the open-circuit current will be small, about 5–15% of the nominally rated current. It increases in direct proportion to the applied voltage and sharply so when saturation is reached as shown by the curve in Fig. 23.

Since very high voltages may arise, the testing of an 'unknown' transformer should be carried out with great care and be started with relatively low applied potentials. The knee of the curve in Fig. 23 is a measure of the nominally rated voltage of the winding.

[940046]

# DESIGNING OSCILLATORS FOR PICs

By A. Rietjens

**Peripheral Interface Controllers, PICs®, from Microchip are currently in the centre of attention. In descriptions of these devices an important aspect is seldom mentioned: the design of the clock oscillators. This article aims at putting this right.**

Peripheral Interface Controllers contain a general purpose clock oscillator. This oscillator is controlled by an RC network, a quartz crystal or a ceramic filter. The clock signal may also be taken from an external generator. In the programming of the EPROM version of the PIC it must be stated which type of oscillator is used. The One Time Programmable (OTP) and QTP versions are available in four different types: RC, LP, XT or HS. Each of these types is suitable for one of the four oscillator variants.

## RC oscillators

RC oscillators are an economical design for those applications where accuracy is not too important. When this oscillator is to be used, the RC or EPROM version of the PIC must be purchased. If the EPROM variant is used, the correct bit combination must be selected during programming.

The oscillator frequency depends on four quantities: the voltage, the temperature, the value of the capacitor and the value and type of the resistor. The design of the oscillator is shown in **Fig. 1**. Since at resistance values of  $>1\text{ M}\Omega$  the oscillator becomes vulnerable to noise, temperature variations and humidity, it is advisable to use values of 5–100 k $\Omega$ . Values  $<3\text{ k}\Omega$  may cause instability. **Table 1** gives a correlation of the capacitance, resis-

tance and oscillator frequency. The frequency may be 0–4 MHz.

## Quartz & ceramic oscillators

Ceramic and crystal oscillator have a number of advantages over RC types. Especially their stability and accuracy make them very suitable for circuits that are to be used in a wide variety of conditions. For this type of oscillator, the XT, HS or LP version of the PIC must be purchased. The EPROM version with accurate configuration may also be used. The XT version may be used with crystal frequencies of 0.1–4 MHz, the HS version from 4 MHz to 20 MHz and the LP version from d.c. to 40 kHz. If an external oscillator is used, all these versions can operate down to d.c.

The basic circuit of the oscillator is shown in **Fig. 2**. Sometimes a resistor has to be added to suppress oscillation at overtones. When the HSD version is used,  $R_s$  must always be fitted; its value should be between 100  $\Omega$  and 1 k $\Omega$ . **Table 2** gives the optimum values of  $C_1$  and  $C_2$  if a ceramic resonator is used, while **Table 3** gives these values when a crystal is used.

## External oscillator

If a central clock oscillator is used in the processor system, it is convenient if the PIC can also employ this. The external clock signal must then be

RC OSCILLATOR FREQUENCY VARIATION FROM UNIT TO UNIT

Cext	Rext	Average	
		Fosc @ 5V, 25°C	
20pf	3,3k	4,71 Mhz	$\pm 28\%$
	5k	3,31 Mhz	$\pm 25\%$
	10k	1,91 Mhz	$\pm 24\%$
	100k	207,76 Khz	$\pm 39\%$
100pf	3,3k	1,65 Mhz	$\pm 18\%$
	5k	1,23 Mhz	$\pm 21\%$
	10k	711,54 Khz	$\pm 18\%$
	100k	75,62 Khz	$\pm 28\%$
300pf	3,3k	672,78 Khz	$\pm 14\%$
	5k	489,49 Khz	$\pm 13\%$
	10k	275,73 Khz	$\pm 13\%$
	100k	28,12 Khz	$\pm 23\%$

940106 - T1

Table 1.

CAPACITOR SELECTION FOR CERAMIC RESONATORS

Oscillator Type	Resonator Frequency	Capacitor Range C1 = C2
XT	455 KHz	150 - 330 pF
	2,0 MHz	20 - 330 pF
	4,0 MHz	20 - 330 pF
HS	8,0 MHz	20 - 200 pF

940106 - T2

Table 2.

CAPACITOR SELECTION FOR CRYSTAL OSCILLATOR

Osc Type	Freq	C1	C2
LP	32 KHz	15 pF	15 pF
XT	100 KHz	15 - 30 pF	200 - 300 pF
	200 KHz	15 - 30 pF	100 - 200 pF
	455 KHz	15 - 30 pF	15 - 100 pF
	1 MHz	15 - 30 pF	15 - 30 pF
	2 MHz	15 pF	15 pF
	4 MHz	15 pF	15 pF
HS	4 MHz	15 pF	15 pF
	8 MHz	15 pF	15 pF
	20 MHz	15 pF	15 pF

940106 - T3

Table 3.

applied to input OSC1. Output OSC2 remains unused. Only XT, HS, LP and EPROM versions of the PIC can be used for this configuration.

[940106]

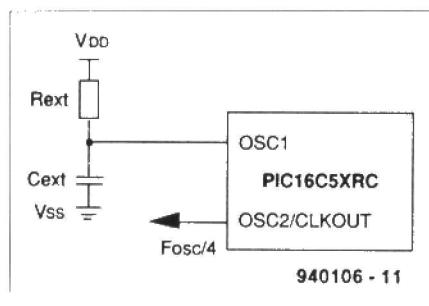


Figure 1.

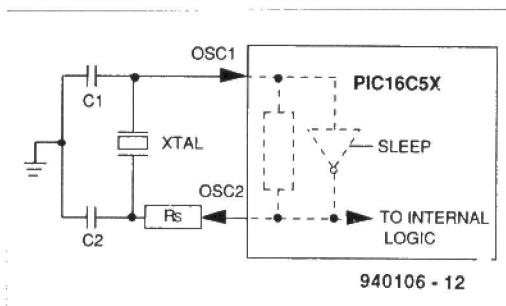


Figure 2.

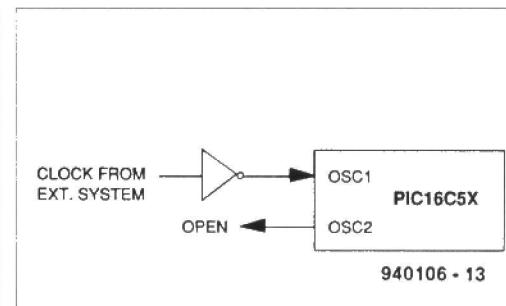


Figure 3.

# PIC® PROGRAMMING COURSE

## PART 3: INSTRUCTION SET

**So far in the course we have been dealing with the hardware structure of the PIC processors. This third instalment, and the one to come, will deal with programming aspects and the PIC instruction set. This instalment also introduces the MPALC assembler for PIC devices, which may be obtained on diskette.**

By our editorial staff.

Source: Microchip Technology Inc.

The instructions in the instruction set of most processors usually consist of two parts: an opcode (the instruction proper), and an operand (such as a memory location or a register). The operand is the object of the opcode. Most microprocessors and microcontrollers use one or more bytes for opcodes and operands. Not so with the PIC16C5x processors, which work with 12-bit wide words containing the instruction code and the operands. This approach has advantages as well as disadvantages. For example, the 12-bit structure limits the number of possibilities for the instruction code to 33. On the other hand, it has the advantage of offering very fast instruction processing because all information is fetched in one go.

The instructions used by the PIC16C5x may be divided into three groups:

- byte oriented register file instructions;
- bit oriented register file instructions;
- constants and control instructions.

A marked difference with other processors is noted as regards the byte oriented instructions. Usually, a 'working register' ('W' register in PIC devices; 'accumulator' in most others) is used, for in-

stance, when adding two numbers. With PIC devices, the programmer has the option of storing the result into the W register or into the register file specified in the operand. In the instruction code, the choice is made with the aid of the 'destination bit', d. Unfortunately, Microchip Technology has left the declaration of the d bit to the programmer. Consequently, the 'd' bit has to be declared as follows at the start of every program:

```
;rule destination
W equ OH ;destination = W
F equ 1H ;destination = f
```

The PIC instruction set is summarized in **Tables 1, 2 and 3**. The commands and directives used by Microchip's 'MPALC' PIC assembler are listed in **Tables 4, 5, 6 and 7**. A number of these will be discussed further on in this article.

### For example: a flashing LED

The outputs of a PIC16C5x processor can drive loads up to 20 mA. However, the maximum current drawn by the PIC device must remain below 50 mA, while the current through the GND (ground) connection must remain smaller than 150 mA.

A programming example, LED\_SMPL.ASM (on the course diskette), works in conjunction with the hardware arrangement shown in **Fig. 1**. An LED and a 330- $\Omega$  series resistor are connected between the positive supply line (+5 V) and I/O port line RA0. All other I/O pins are strapped to +5 V via 10-k $\Omega$  pull-up resistors. A press-key is connected between RA1 and ground. The circuit is built on an experimentation board for PICs described in Ref. 1.

The function of the program is simple: arrange for the LED to start flashing as

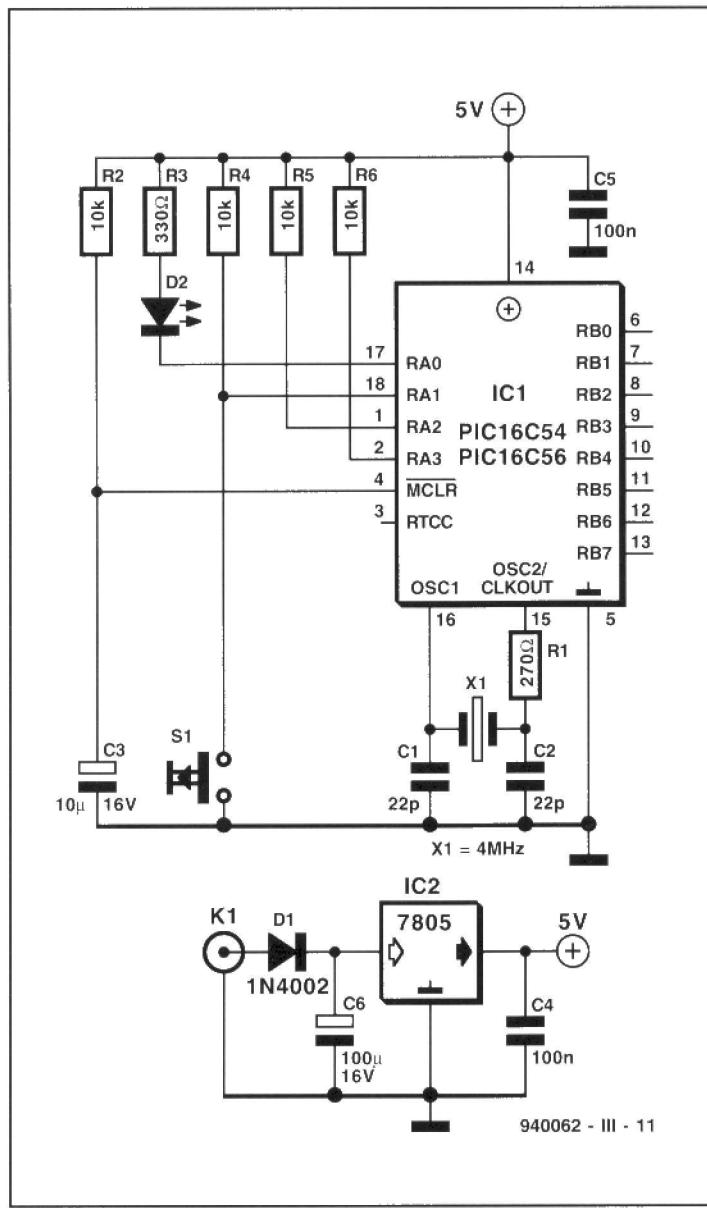


Fig. 1. Circuit diagram of the PIC-based LED flasher.

soon as the press-key is actuated. The example program is assembled as follows:

```
MPALC LED_SMPL.ASM
<RETURN>
```

While programming the PIC, make sure that the XT (quartz crystal) oscillator option is used.

The operation of the program is easily followed by referring to the listing shown in **Fig. 2**. Lines 1 through 16 contain the assembler instructions which determine the appearance of the listing. The comment with these lines is mostly self-evident. Next, the RESET vectors are declared. The declarations depend on the controller used, and are programmed via a constant called 'controller'. In the present example, 'controller' takes a value of 56. In the subsequent 'if...endif' construction, a second constant, 'Adr\_Reset' is defined, which is dependent on the value of 'controller', and serves to enable the assembler to include the reset vectors in the proper locations.

The directive 'list p=16C' is a little unusual. Why the processor type is defined using a 'list' instruction will probably remain a secret kept by the designers of the assembler.

More constants are declared up to line 77. Well-commented declarations are essential to get a good insight into the structure of the program, and are essential for efficient program development and debugging. Also, the declarations may make use of the assembler's computing capabilities, for example,

```
characters/line    equ 80
lines/page       equ 25
characters/page   equ characters/line * lines/page
```

This is the correct approach. By contrast, the following declaration is incorrect:

```
characters/page  equ 2000
```

As already mentioned with the description of the PIC hardware, a CALL instruction can only 'jump' within

**Table 1. Byte-oriented file register operations**

Mnemonic, operand(s)	Name, operation	Status Affected	
ADDWF	f, d	Add W and f	C, DC, Z
ANDWF	f, d	AND W and f	Z
CLRF	f	Clear f	Z
CLRW	-	Clear W	Z
COMF	f, d	Complement f	Z
DECFSZ	f, d	Decrement f, Skip if zero	-
DECF	f, d	Decrement f	Z
INCF	f, d	Increment f	Z
INCFSZ	f, d	Increment f, Skip if zero	-
IORWF	f, d	Inclusive OR W and f	Z
MOVF	f, d	Move f	Z
MOVWF	f	Move W to f	-
NOP	-	No Operation	-
RLF	f, d	Rotate left f	C
RRF	f, d	Rotate right f	C
SUBWF	f, d	Subtract W from f	C, DC, Z
SWAPF	f, d	Swap halves f	-
XORWF	f, d	Exclusive OR W and f	Z

**Table 2. Bit-oriented file register operations**

Mnemonic, operand(s)	Name, operation	Status Affected	
BCF	f, b	Bit clear f	-
BSF	f, b	Bit set f	-
BTFSZ	f, b	Bit Test f, Skip if Clear	-
BTFSZ	f, b	Bit test f, Skip if set	-

**Table 3. Literal and control operations**

Mnemonic, operand(s)	Name, operation	Status Affected	
ANDLW	k	AND literal and W	Z
CALL	k	Call subroutine	-
CLRWD	-	Clear watchdog timer	TO, PD
GOTO	k	Go To address (k = 9 bit)	-
IORLW	k	Inclusive OR Literal and W	Z
MOVLW	k	Move Literal to W	-
OPTION	-	Load OPTION register	-
RETLW	k	Return, place Literal in W	-
SLEEP	-	Go into standby mode	TO, PD
TRIS	f	Tristate port f	-
XORLW	k	Exclusive OR Literal and W	Z

**Table 4. Data directives**

data	<expr>	Create a 12-bit data value or character string
zero	<mem units>	Initialize with zero <mem units> of program space
set	<label> ... <expr>	Define assembler value
res	<mem units>	Reserve words of program space
equ	<label> ... <expr>	Define an assembler constant
include	"<file_name>"	Include a file into the assembly source flow

**Table 5. Listing directives**

list	<option>	Set various list control options
page		Force a page eject
title	"title text"	Define a new title for the listing header
subtitl	"subtitle text"	Define a new subtitle for the listing header

## PIC16C5x PROGRAMMING

This short course is aimed at providing an introduction into programming and hardware aspects of the PIC16C5x family of microcontrollers manufactured by Microchip Technology Inc.

An **assembler** is offered on disk in support of the course. This assembler is distributed with the permission of Microchip Technology Inc., and supports the PIC16C5x and PIC16Cxx series of controllers. It offers a full featured macro and conditional assembly capacity. It can also generate various object code formats including several hex formats to support Microchip's proprietary development tools as well as third party tools. Also supported are hex (default), decimal and octal source and listing formats. An assembler users manual is available from Microchip Technology distributors for detailed support. The disk also contains a software **simulator**.

The PIC programming course disk may be obtained through the *Elektor Electronics Readers Services* under order number **946196-1**. For price and ordering information, see page 70 of this issue.

The files produced by the assembler can be downloaded to the **PIC programmer** described in *Elektor Electronics* March 1994.

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THE COURSE!**

the first half of a program memory page. It is, therefore, wise to declare all subroutines at the start of the program. The 'ORG' instruction in line 86 tells the assembler to set the internal program counter to the indi-

**Table 6. Control directives**

if	<expr>	Start of a conditional assembly block
else		Start of an alternate conditional assembly block
endif		Terminate a conditional assembly block
org	<label> ... <addr>	Set absolute address for following block code
end		Terminate assembly code block

**Table 7. Macro directives**

macro	<label> .. [<arg>.]<arg> ... ]	Begin a macro body definition
endm		Terminate macro body definition
local	<label>[.<label>] ...	Define assembler labels as local to macro
exitm		Exit macro

cated address, here, 0000. Immediately after this statement, the subroutine 'Wait\_ms' starts. The delay introduced by this subroutine is defined in milliseconds with the aid of a value read from the W register.

## Read instructions

The first instruction in the 'Wait\_ms' subroutine is MOVWF (Table 8). It tells the controller to store the contents of the W register directly at location 'ms'. This location was declared earlier in line 65.

The next instructions (lines 100 and 101) cause a location called 'us' (for microseconds,  $\mu$ s) to be filled with the value 0FEH. Since there is no instruction which enables that to be done directly, an alternative approach is used in which the W register plays an important part. The instruction MOVLW (line 100) puts the constant into the W register.

There are two ways to place the value '0' into the W register; either use MOVLW 000H, or the simpler CLRW instruction. Note, however, that CLRW also sets the Z flag.

Another instruction to clear the contents of a memory location in the register file is 'CLRF'. Like CLRW, CLRF does not make use of the W register, and actuates the Z flag.

A final option is the MOVF instruction, which allows the contents of a memory location to be copied into the W register. Alternatively, this instruction enables the memory location included in

the operand, rather than the W register, to act as the 'target'. The result of this instruction is that the contents of a location are simply returned to the same location. This seemingly pointless instruction is useful with, for instance, I/O port operations. One instruction is sufficient to read the logic state of a port, and return the information to the buffer register. The same instruction may also be used to test the contents of a register for the value '0'.

As already mentioned, the subroutine waits the number of milliseconds defined via the W register. This is achieved by using two nested loops. The outer loop (lines 103 through 111) takes exactly 1 ms to complete if a clock frequency of 4 MHz is used. This loop is called as many times as the value contained in the W register, via lines 110 and 111. The number of iterations of the inner loop is not stored as a constant in the 'us' register, but added to the constant of the register. This is done on purpose to allow a correction to be made to compensate for the time needed to start the entire subroutine. The subroutine is finished if location 'us' reaches the value 00H.

## Arithmetic instructions

The arithmetic instructions offered by PIC processors are limited to ADDWF and SUBWF, and their derivates INCF and DECF. An application of the ADDWF instruction may be found in

```

1 title "Sample flashing LED" ; Program title
2 subtitl «Declarations» ; Program subtitle
3
4 ; Listing Options for MPALC assembler
5 list c=136 ; Columns per line
6 list n=60 ; Lines per page
7 list r=HEX ; [HEX,DEC,OCT] ; HEX as default
8 list l=ON ; [ON / OFF] ; Listing ON
9 list x=ON ; [ON / OFF] ; Macro expansion on
10 list t=ON ; [ON / OFF] ; Truncate listing lines
1 list e=0 ; [0,1,2,3] ; 0 = Report all Messages
2 ; 1 = Report Warnings,
; 2 = Report fatal, criticals
; 3 = Report criticals
3
4
5
6 page ; New Page
7
8 ; select controller
9 controller equ 56 ;54: PIC 16C54, 55: PIC 16C55 ...
20
1 if controller == 54 ; PIC 16C54
2 list p=16C54 ;
3 Adr_Reset equ 01FFH ;
4 endif
5 if controller == 55 ; PIC 16C55
6 list p=16C55 ;
7 Adr_Reset equ 01FFH ;
8 endif
9 if controller == 56 ; PIC 16C56
10 list p=16C56 ;
1 Adr_Reset equ 03FFH ;
2 endif
3 if controller == 57 ; PIC 16C57
4 list p=16C57 ;
5 Adr_Reset equ 07FFH ;
6 endif
7
8 ; Main declarations
9
10 ; Destination of Byte-Oriented File Register Operations
11 W equ 00H ; Destination is W Register
12 F equ 01H ; Destination is F Register
13
14 ; Directions of I/O - Ports
15 Input equ 01H ; Input
16 Output equ 00H ; Output
17
18 ; Register file declarations
19
20 ; Operational Register File
21 INDIRECT equ 00H ; Indirect Data addressing
22 RTC equ 01H ; Real Time Clock/Counter Reg.
23 PC equ 02H ; Program counter
24 STATUS equ 03H ; Status Word Register
25 FSR equ 04H ; File Select Register
26
27 ; I/O Registers (Ports)
28 Port_A equ 05H ;
29 Port_B equ 06H ;
30 Port_C equ 07H ; PIC 16C55/C57 only
2
31
32 ; General Purpose Registers, user defined
33 us_Register equ 009H ;
34 ms_Register equ 00AH ;
35
36 ; Hardware declarations
37
38 LED_B equ 00H ; LED connected to RA0
39 LED_P equ Port_A ; 
40 LED off_time equ 000H ; LED off for 256 ms
41 LED on_time equ 000H ; LED on for 256 ms
42
43 KEY_B equ 01H ; KEY connected to RA1
44 KEY_P equ Port_A ; 
45
46
47 subtitl "Subroutines"
48 page
49
50 ; =====
51 ; Subroutines
52 ; =====
53
54 org 0000H ; Subroutines only in first half
55 ; of page
56
57
58 ; Subroutine Wait_ms
59
60 ; Parameter: ms in W Register
61 ; Return value: 000H
62
63 ; Delay time is 1 ms * (W Register) at Fosc = 4Mhz
64 ; Note: W Register = 000H => 256 ms
65
66
67 Wait_ms movwf ms_Register ; store ms
68 100 movlw 0FEH ; correct call time (incl 1 movlw
69 1 movwf us_Register ; before calling) for first loop
70
71
72 3 W_Loop_ms movlw 0F9H ; 1 loop 249*W_Loop_us+4 cycles
73 4 addwf us_Register,F ;
74
75

```

```

6 W_Loop_us    nop          ; one loop = 4 cycles
7 decfsz us_Register,F   ; us_register - 1, skip if zero
8 goto W_Loop_us
9
110 decfsz ms_Register,F ; ms_register - 1, skip if zero
1 goto W_Loop_ms
2    nop          ; correct time of last ms loop
3
4    retlw 000H
5 ;
6 ;
7
8     subtitle "Main program"
9     page
120
1 ; =====
2 ; Main Program
3 ; =====
4 ;
5 Main_Start      ; Starting after RESET
6     movlw 00EH        ; Set RA0, which is connected to
7     tris Port_A       ; LED, as output
8     goto LED_off      ; Initially: LED off
9
130 Loop          btfsc KEY_P, KEY_B ; Key pressed? (RA1 = 0?)
1     goto Loop
2     ; No, wait until key pressed
3
4     bcf LED_P, LED_B ; LED on
5     movlw LED_on_time ; wait
6     call Wait_ms
7 LED_off         bsf LED_P, LED_B ; LED off
8     movlw LED_off_time ; wait
9     call Wait_ms
140
1     goto Loop
2 ;
3 ; =====
4     org Adr_Reset    ; define reset vector
5 Reset           goto Main_Start ; Start at Main_Start after RST
6 ; =====
7     end

```

**Fig. 2.** Example program for the hardware shown in Fig. 1. The code shown here may be typed in using any ASCII compatible word processor, and is suitable for the Microchip Technology's MPALC assembler found on the PIC programming course disk. Line numbers are added for reference in this article only; they are NOT included in the LED\_SMPL.ASM file on the course disk.

```

; Add two 32-Bit numbers N and Z. Result stored back into N.
; If N+Z > 2**32 the CARRY flag is set
;
; N_LL, Z_LL: Bit 0..7
; N_LH, Z_LH: Bit 8..15
; N_HL, Z_HL: Bit 16..23
; N_HH, Z_HH: Bit 24..31
;
ADD_LL    movf Z_LL, W ; Load W with Z_LL
          addwf N_LL, F ; ADD N_LL and W, store at N_LL
          btfsc 3,0       ; Skip if Carry = 0
          goto CARRY_LH ;
;
          movf Z_LH, W ; Load W with Z_LH
          addwf N_LH, F ; ADD N_LH and W, store at N_LH
          btfsc 3,0       ; Skip if Carry = 0
          goto CARRY_HL ;
;
          movf Z_HL, W ; Load W with Z_HL
          addwf N_HL, F ; ADD N_HL and W, store at N_HL
          btfsc 3,0       ; Skip if Carry = 0
          goto CARRY_HH ;
;
          movf Z_HH, W ; Load W with Z_HH
          addwf N_HH, F ; ADD N_HH and W, store at N_HH
          retlw 000H       ; Return, load W with 000H
;
; Ripple carry routine
;
CARRY_LH  incfcz Z_LH, W ; Load W with Z_LH+1, skip if W=0
          goto ADD_LH
CARRY_HL  incfcz Z_HL, W ; Load W with Z_HL+1, skip if W=0
          goto ADD_HL
CARRY_HH  incfcz Z_HH, W ; Load W with Z_HH+1, skip if W=0
          goto ADD_HH
          setc             ; overflow => carry = 1
          retlw 000H       ; Return, load W with 000H

```

**Fig. 3.** PIC assembly code for a program which adds two 32-bit numbers.

<b>MOVWF</b>	<b>Move W to f</b>	
<b>Syntax</b>	movwf f	<b>Status bits:</b> none
<b>Description</b>	Move data from W register to register f	
<b>Example</b>	movwf ms_Register	

<b>MOVLW</b>	<b>Move Literal to W</b>	
<b>Syntax</b>	movlw k	<b>Status bits:</b> none
<b>Description</b>	The 8-bit literal k is loaded into W register	
<b>Example</b>	movlw 0FEH	

<b>CLRW</b>	<b>Clear W register</b>	
<b>Syntax</b>	clrw	<b>Status bits:</b> Z
<b>Description</b>	W register is cleared. Zero bit (Z) is set	
<b>Example</b>	clrw	

<b>CLRF</b>	<b>Clear f and Clear d</b>	
<b>Syntax</b>	clrf f,d	<b>Status bits:</b> none
<b>Description</b>	Contents of register f are set to 0 d = 0: contents of both data memory location f, and W register are set to 0 d = 1: contents of register f are set to 0	
<b>Example</b>	clrf ms_Register	

<b>MOVF</b>	<b>Move f</b>	
<b>Syntax</b>	movf f,d	<b>Status bits:</b> Z
<b>Description</b>	d = 0: move contents of register f, result stored in W d = 1: move contents of register f, result stored back in f	
<b>Example</b>	movf Port_B, W	

<b>ADDWF</b>	<b>Add W to f</b>	
<b>Syntax</b>	addwf f,d	<b>Status bits:</b> C, DC, Z
<b>Description</b>	Add contents of the W register to register f d = 0: result stored in W register d = 1: result stored back in register f	
<b>Example</b>	addwf us_Register, F	

<b>SUBWF</b>	<b>Subtract W from f</b>	
<b>Syntax</b>	subwf f,d	<b>Status bits:</b> C, DC, Z
<b>Description</b>	Subtract the W register from register f d = 0: result stored in W register d = 1: result stored back in register f	
<b>Note</b>	The subtraction is carried out according to the 2's complement method. The Carry bit is set if the subtraction did not produce an overflow: f > W => C = 1, Z = 0 f = W => C = 1, Z = 1 f < W => C = 0, Z = 0	
<b>Example</b>	subwf us_Register, F	

<b>INCF</b>	<b>increment f</b>	
<b>Syntax</b>	incf f,d	<b>Status bits:</b> Z
<b>Description</b>	Increment contents of register f d = 0: result stored in W register d = 1: result stored back in register f	
<b>Example</b>	incf ms_Register, F	

<b>DECWF</b>	<b>decrement f</b>	
<b>Syntax</b>	decf f,d	<b>Status bits:</b> Z
<b>Description</b>	Decrement register f d = 0: result stored in W register d = 1: result stored back in register f	
<b>Example</b>	decf ms_Register, F	

line 104, where a value OF9H (copied into W in line 103) is added to the contents of location 'us'.

All arithmetic instructions allow either the W register or the f register in the operand to function as the 'target'. That enables a certain value to be added to several f registers in one go.

Unfortunately PIC processors lack instructions of the type 'add with carry' and 'subtract with carry'. Consequently, adding numbers which are wider than 8 bits requires the carry flag to be processed separately.

**Figure 3** shows an example of a program in which two 32-bit numbers are added. These numbers are 'Z' and 'N'. 'Z' consists of the bytes Z\_HH, Z\_HL, Z\_LH and Z\_LL. The same goes for 'N'.

When using the SUBWF instruction, it should be noted that this is performed according to the 'two's com-

plement' method. Consequently, the carry flag is actuated inversely.

The use of the DECF and INCF instructions should be self-evident. These instructions decrease or increase the contents of a memory location by one, respectively. Here, too, the result is stored into the f register stated in the operand, or into the W register. If the result equals 0, the Z flag is actuated.

(940062-3)

#### Reference:

1. Experimentation board for PICs, Elektor Electronics July/August 1994.

**Continued in the November 1994 issue.**

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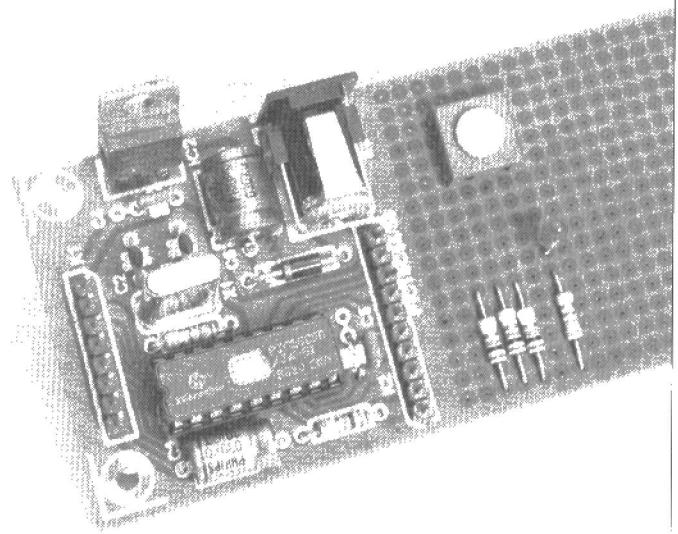


Fig. 4. The PIC-based LED flasher is best built on a PIC experimentation board (Ref. 1).

## Microchip announces new PIC16CR57A 8-bit microcontroller

MICROCHIP'S low-cost PIC16CR57A 8-bit microcontroller is ideal for I/O intensive, low-power applications. The new 8-bit ROM-based microcontroller uses an advanced 0.9-micron fabrication process to achieve greatly improved electrical performance with lower power consumption and a wider operating voltage range.

Running at up to 20 MHz, with faster instruction execution than any other 8-bit RISC microcontroller in its class, the PIC16CR57A operates from 2.5 to 6.25 V sources and features a power-down (sleep) mode that further reduces power consumption. On-chip memory facilities include 2,048 12-bit wide words of masked ROM for program storage, and 72 bytes of static RAM for data. On-chip peripherals include an 8-bit real-time clock/counter with programmable prescaler, an oscillator start-up timer, a watchdog timer

with on-chip RC oscillator and 20 I/O lines with individual directional control. In addition, the PIC16CR57A is socket and software compatible with Microchip's one-time programmable PIC16C57 microcontroller,

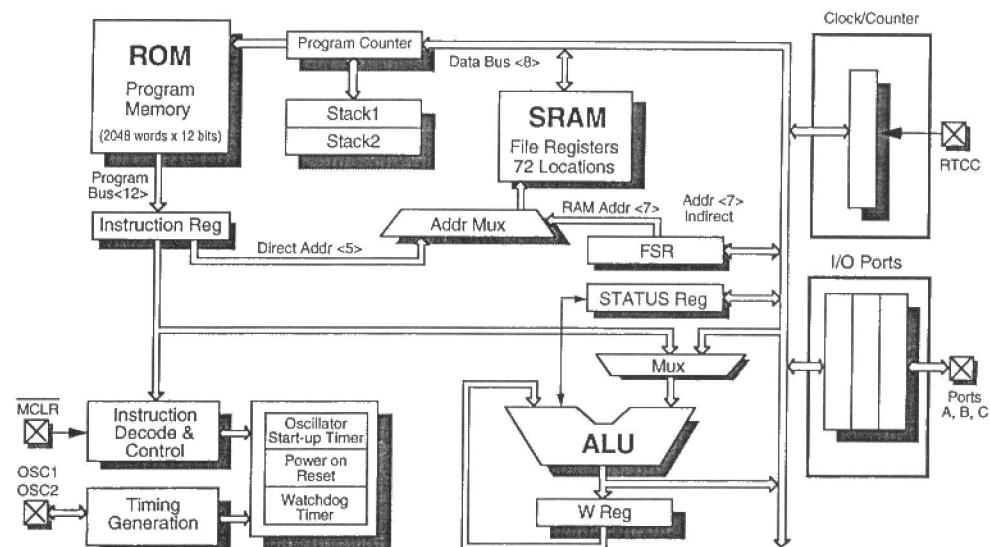
and 100% code compatible with the 18-pin 16CR54 ROM, providing a simple upgrade path to existing users.

**Arizona Microchip Technology Ltd., Unit 3, The**

**Courtyard Meadowbank, Furlong Road, Bourne End, Bucks SL8 5AJ, England.**

**Tel. (0628) 850303, fax: (0628) 850178.**

## PIC16CR57A Architecture



940062-III-12

# TV LINE MONITOR

**Measurements on TV signals are notoriously difficult. Even if you have an oscilloscope with a trigger button marked 'TV' it is practically impossible to select a particular line from the picture signal. That problem is solved once and for all by the TV line monitor described in this article, because it allows any line in the composite video signal to be selected in a simple manner.**

**Design by J. Matus**

FOR a well-founded verdict on the operation of a TV set it is often required to perform measurements on individual lines in the video signal as processed by the set. For this purpose, a number of special test signals (insertion test signals, ITSs) are included in nearly every TV broadcast, whether by satellite or terrestrial. These signals are contained in picture lines which

are normally invisible to the viewer, i.e., they fall outside the actually viewed raster. The TV technician, however, views them on an oscilloscope. The basic functions offered by the ITSs will be discussed further on.

The picture line monitor is a handy and multi-functional tool for repairing and adjusting TV sets and other video equipment, such as video recorders

(VCRs). The TV line monitor is based on a PIC16C54, a type of microcontroller which has been used on several occasions at the heart of different circuits described in *Elektor Electronics*. The PIC comes ready-programmed through our Readers Services, and reduces the IC count in the circuit to three (well, actually four if you include the voltage regulator). The line monitor enables an oscilloscope to be triggered at the start of the TV line selected by you, the user. The TV line you wish to view on the scope is selected with the aid of two press-keys, and is indicated on a readout consisting of three 7-segment LED displays.

The circuit diagram of the TV line selector is given in Fig. 1. Broadly speaking, the circuit consists of two parts: a synchronisation separator and a processor (with LED readout) which acts as a general control. The composite video signal (CVBS) is applied to the circuit via socket K<sub>1</sub>. To keep the loop-through connection to the oscilloscope as simple as possible, the CVBS signal reappears on K<sub>2</sub>. A simple RC filter, R<sub>17</sub>-C<sub>2</sub>, removes spurious pulses and other noise from the video signal. The 'clean' signal reaches the CVBS input of IC<sub>1</sub>, an LM1881, via coupling capacitor C<sub>3</sub>. The LM1881 from National Semiconductor is designed specially to unravel composite video signals. The four outputs of this IC supply (1) the composite synchronisation signal, (2) the vertical synchronisation pulses, (3) a colour burst marker and (4) an odd/even field marker. These signals provide all the information necessary to determine the timing of a composite video signal. The TV line monitor only uses the composite and the vertical synchronisation signals. The position of the colour burst is of no consequence to the circuit. Likewise, the odd/even field signal is less suitable for use here, mainly because it tends to be erratic if the video signal contains noise. This was considered an important drawback for a test instrument.



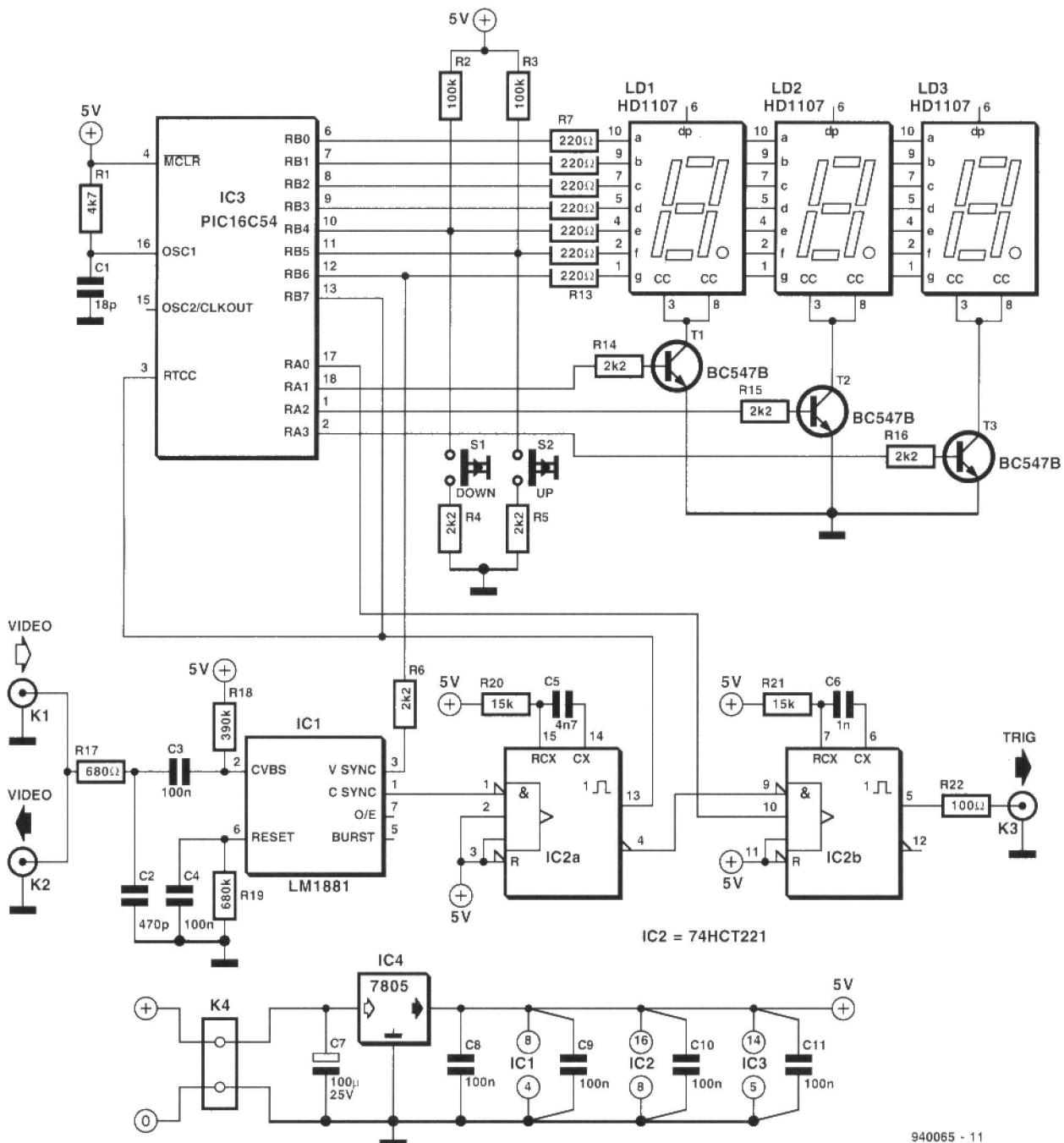


Fig. 1. Circuit diagram of the TV line monitor. The PIC processor, IC3, is supplied ready-programmed.

The composite sync signal is applied to monostable multivibrator IC2a, whose monotime equals about three quarters of a picture line. This time is used to suppress the half-line pulses which occur during the field flyback period. The output of the monostable supplies a clean horizontal sync signal, which can be used straight away by the processor.

The timing diagram in Fig. 2 shows how the odd/even field changeover is usually marked in the signal. During the field flyback period, a number of extra sync pulses are inserted into the

horizontal synchronisation signal, half-way the line period.

Since it is essential for the TV line monitor to detect the field changeover, the processor has to restore the relevant signal from the vertical and horizontal synchronisation pulses (remember, the odd/even field signal supplied by the LM1881 is not used). Figure 2 also indicates a delay of half a line period in the vertical synchronisation signal. This time has to be compensated to make sure that the trigger pulse for the oscilloscope is properly timed.

## MAIN SPECIFICATIONS

Video standard:	PAL
Line number display:	3 x 7-segment LED
Processor:	PIC16C54
Controls:	two press-keys
Field:	selectable, odd or even
Picture line:	selectable, 1 through 625
Output:	digital trigger pulse
Detection:	no or bad input signal

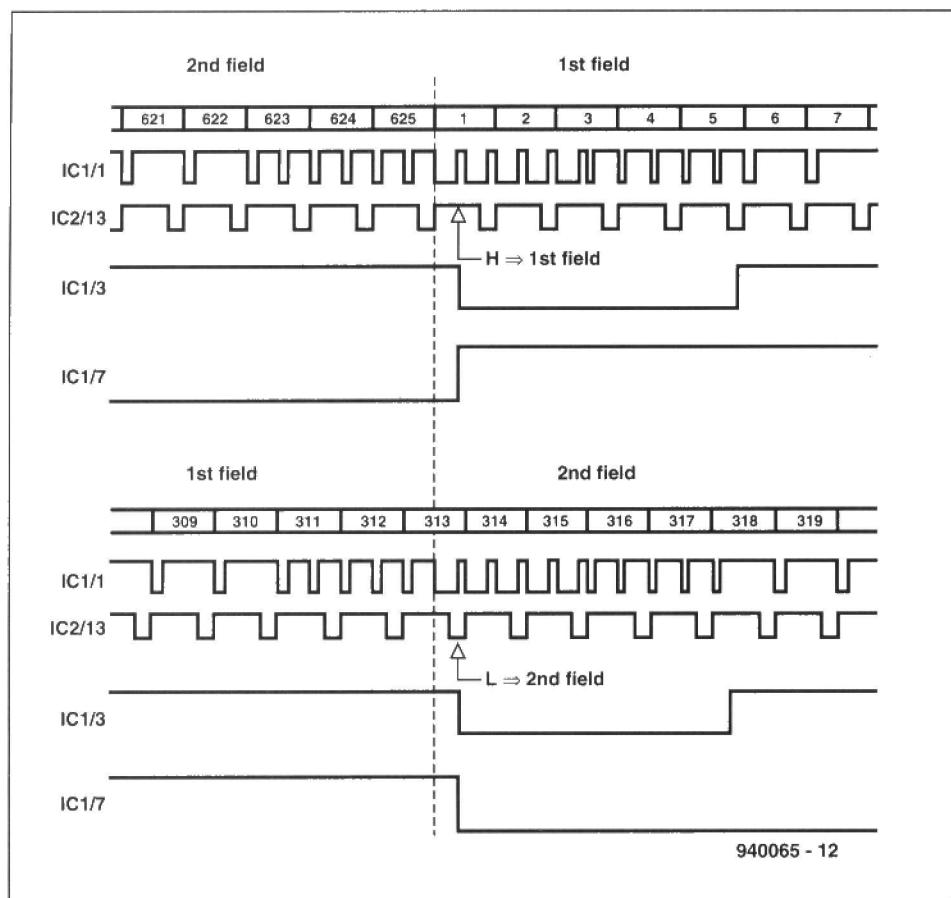


Fig. 2. The change from an odd-numbered to an even-numbered field in an interlaced TV picture is marked by extra horizontal synchronisation pulses which are inserted at about half-way the line period. These pulses appear around the vertical sync pulse.

### The processor: heart of the circuit

As already mentioned, a PIC processor is used for all computing and control functions in the circuit. These functions are:

- driving the display in multiplex mode;
- scanning the press-keys for activity;
- counting the picture lines;
- enabling the trigger pulse.

All functions are carried out by a clever piece of software and the PIC's on-board 8-bit timer. A problem with the PIC processor used is that it can not handle interrupts. Consequently, the software must use 'polling', i.e., very frequent checking whether the desired picture line is already present at the input. Polling is an acceptable alternative if interrupts are not available, but it does take time. As illustrated in Fig. 3, it can lead to a large timing error. Obviously, the fastest processor response is obtained if the desired counter state is reached at point 'A'. If the state is reached at point 'B', a considerable delay is introduced because the comparator has to wait for the next polling cycle. This

delay would cause an amount of jitter in the trigger pulse that can not be tolerated in a test instrument. Hence, a trick had to be devised to prevent gross timing errors. The solution is simple as well as ingenious: instead of generating a trigger pulse, the processor only

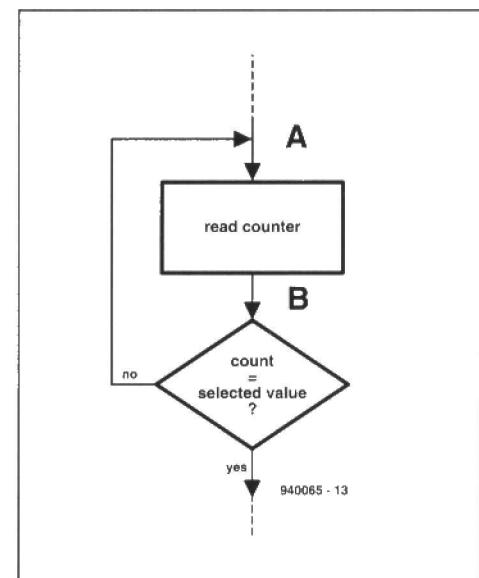


Fig. 3. Polling may cause large variations in the time needed by the processor to respond to a counter state match. This flow diagram shows how the delay is introduced.

enables a monostable ( $IC_{2b}$ ) which does so. The monostable is started without any delay by the horizontal synchronisation pulse. The timing is illustrated in Fig. 4. The 'only' task of the software is to enable the monostable in time. That does, however, create some exacting demands on the speed of the processor, and the compactness of the program executed. Provided it is well written, the software should work reliably despite fairly large variations of the clock frequency. The present circuit works well at clock frequencies between 3 MHz and 5 MHz, allowing the inexpensive RC oscillator variant of the PIC processor

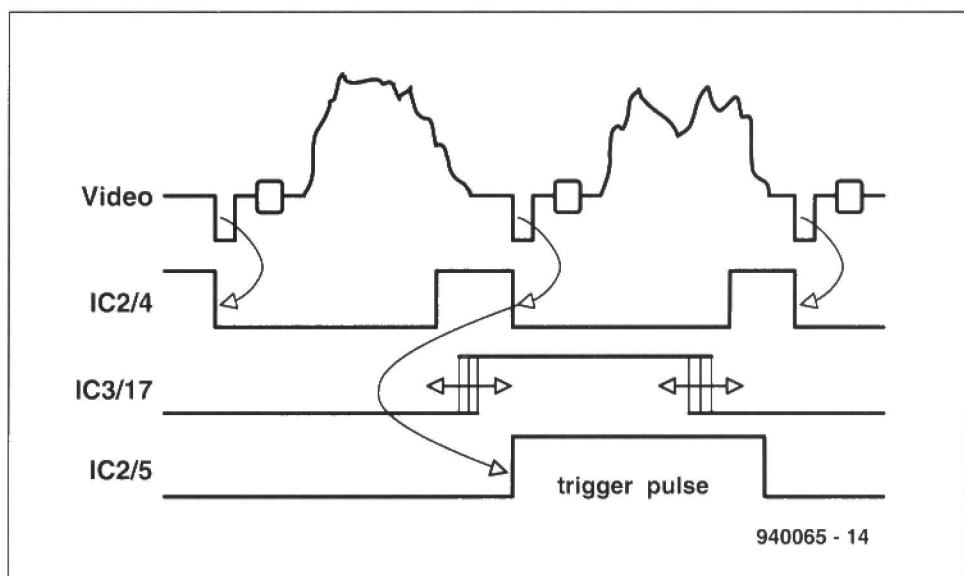


Fig. 4. After the monostable has been enabled, the horizontal sync pulse causes the scope trigger pulse to be generated.

to be used without reducing the repeatability of the circuit.

## Ease of use

The TV line monitor is controlled with the aid of two press-keys marked '+' (up) and '-' (down). The picture line number selected in this way appears on a bright LED display. Any time a key is pressed, the line number is increased (+) or decreased (-) by one. If you keep a key pressed, the line number will step up or down automatically at a rate of two per second. If you keep the key pressed longer than 2.5 s, the auto-step speed goes up to 25 lines per second. The other field is selected by pressing both keys at the same time. If a suitable video signal is not present at the input, the circuit shows a moving bar which travels round the outer display segments.

Finally, note that the circuit is only capable of recognising both fields in a picture if the input signal meets the PAL standard as regards interlacing.

## Action!

Having dealt with the design background of the circuit, it is time to discuss more practical things, i.e., the construction and use of the TV line monitor.

The artwork of the single-sided printed circuit board designed for the instrument is shown in Fig. 5. All components, including the three displays, the three 'RCA' sockets and the two keys, are accommodated on the board.

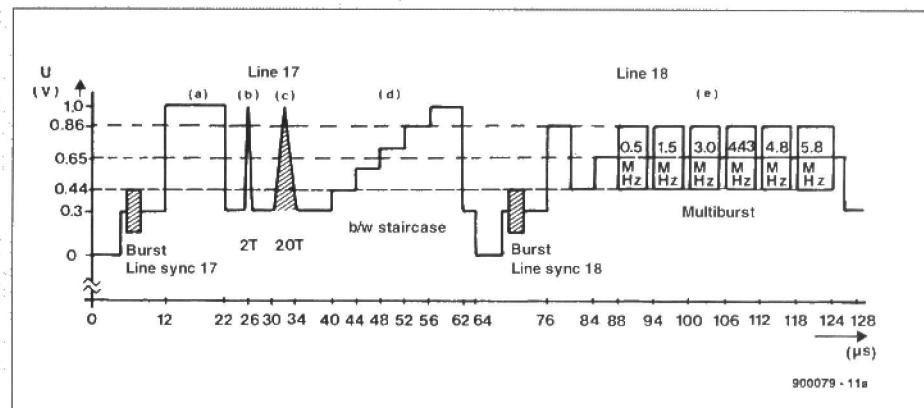
Start the construction by fitting the five wire links. Next, fit all passive components at the proper locations (refer to the component overlay on the board and as shown in Fig. 5). Finally, mount the active parts, the sockets and the PCB terminal block. That completes the construction. Since there are no adjustment points, the circuit is then ready for use.

Connect the circuit to a mains adapter capable of supplying an output voltage of about 8 V d.c. at a current of at least 100 mA. Connect a composite video signal (PAL standard) to socket K<sub>1</sub>. Connect the input of the oscilloscope to K<sub>2</sub>. Next, connect K<sub>3</sub> to the external trigger input of the oscilloscope. Select external triggering on the scope, and set it for a sensitivity of 0.5 V/div., d.c. coupled.

Switch on the line monitor, and check that the LED display reads '1'. The contents of the same line should be visible on the oscilloscope screen. Depending on the timebase setting, successive lines may also appear on the screen. If an unsuitable video signal is applied to the circuit, the outer segments of display LD<sub>1</sub> will go on and

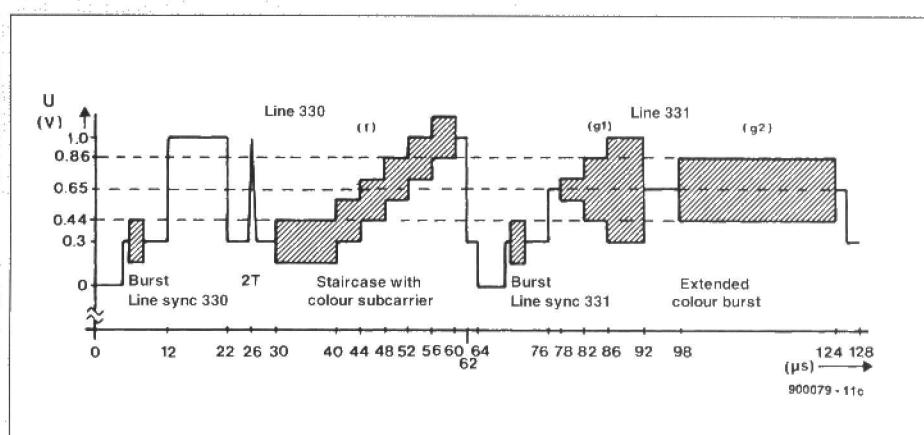
## INSERTION TEST SIGNALS

Although the vast majority of TV viewers will never notice, nearly every TV picture contains a large number of special measurement signals transmitted in two pairs of successive lines, 17-18 and 330-331. The structure and function of these insertion test signals (ITSs) is usually based on CCIR recommendation 473-3.



Picture lines 17 and 18 may be used by the TV technician to test a large number of receiver functions. The black/white bar (a) is a reference to establish the maximum black and white levels. The 2T pulse (b) is test signal with sine-shaped edges and a total duration of 0.2 μs. It is used to determine the picture resolution. An attenuation of 20% is still tolerable. The 20T pulse (c) is used to test the response of amplifiers to luminance and chrominance signals. The next test signal is a monochrome staircase consisting of 140-mV steps. Finally, test signal (e) contains a sequence of fixed frequency bursts ranging from 500 kHz to 5.8 MHz. This 'multi-burst' signal serves to ascertain the frequency-dependent behaviour of the video amplifiers.

Picture line 22 is usually empty, i.e., it contains no video information. It has a function, though, enabling the total noise contribution of the receiver to be checked.



Picture lines 330 and 331 may be used for two basic measurements. Line 330 contains the same 'max. black/white' and 2T pulses as line 17. Next comes the colour burst staircase (f) from which the colour separation circuit in the TV set should deduce a clean 30-μs pulse. The last test signals are (g1) and (g2) in picture line 331. These enable interference between chrominance and luminance signals to be traced.

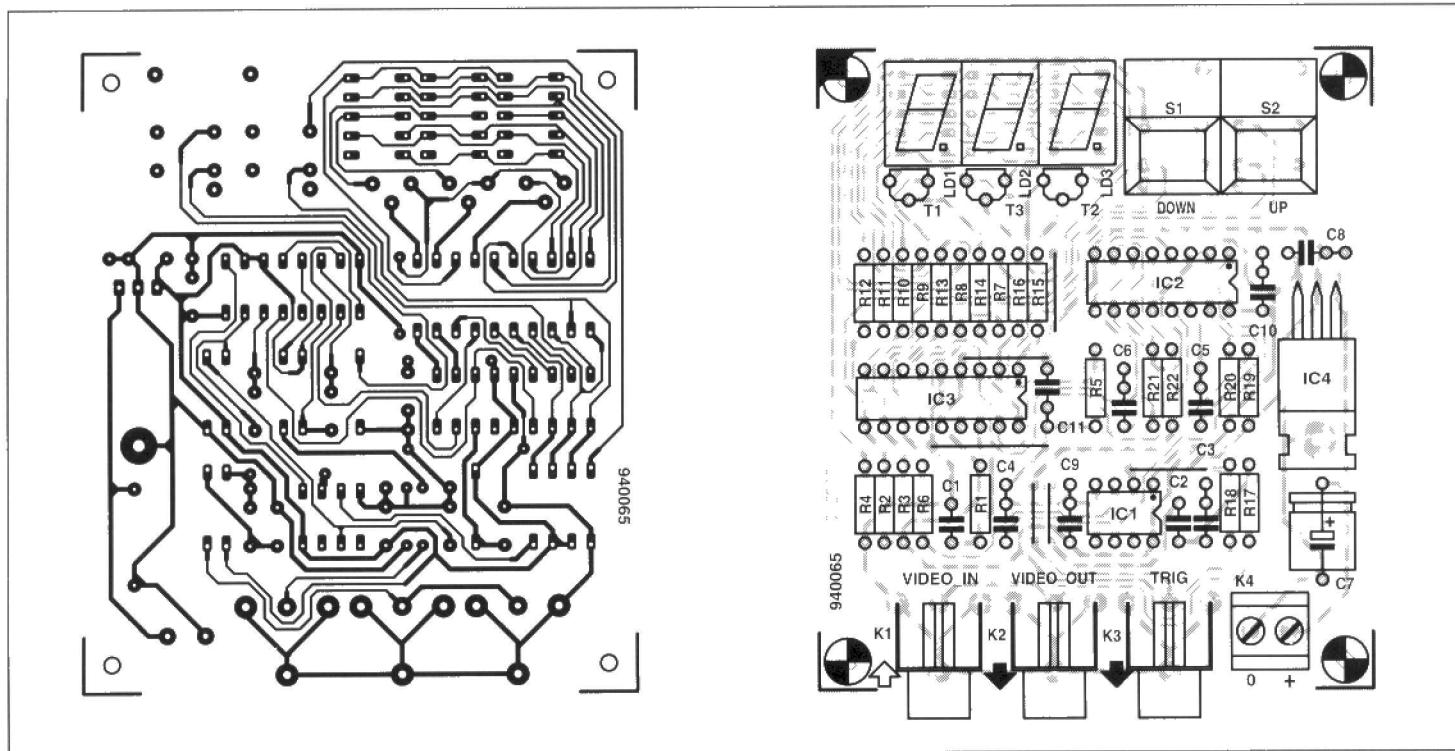


Fig. 5. Component mounting plan and track layout of the PCB designed for the circuit.

off describing a circle. If a correct signal is applied, however, and the circuit is fully functional, any line number can be selected very quickly by pressing the '+' and '-' keys and watching the LED display. (940065)

#### For further reading:

*Colour television*, by Geoffrey Hutson, Peter Shepherd and James Brice. McGraw-Hill Book Company. ISBN 0-07-084199-3.

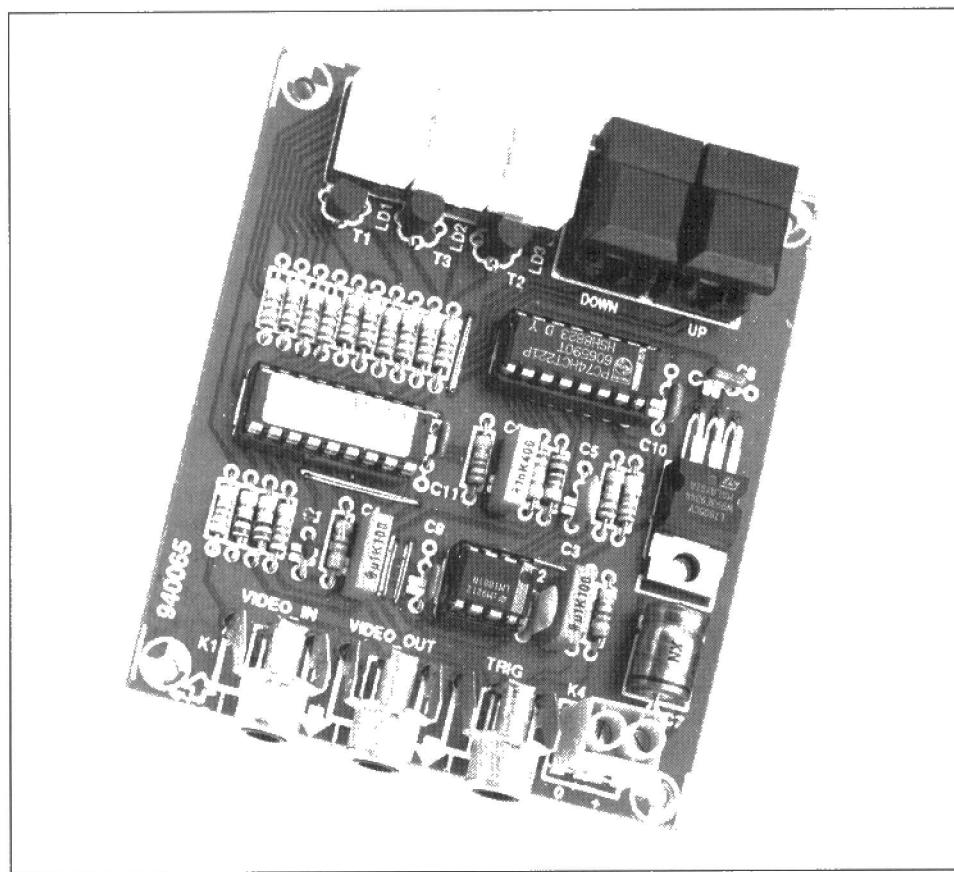


Fig. 6. Completed prototype. Note the compactness of the circuit.

## COMPONENTS LIST

### Resistors:

R1 = 4kΩ  
R2;R3 = 100kΩ  
R4;R5;R6;R14;R15;R16 = 2kΩ  
R7-R13 = 220Ω  
R17 = 680Ω  
R18 = 390kΩ  
R20;R21 = 15kΩ  
R22 = 100Ω

### Capacitors:

C1 = 18pF  
C2 = 470pF  
C3;C4;C8-C11 = 100nF  
C5 = 4nF7  
C6 = 1nF  
C7 = 100μF 25V

### Semiconductors:

T1;T2;T3 = BC547B  
IC1 = LM1881 (National Semiconductor)  
IC2 = 74HCT221  
IC3 = PIC16C54 (programmed; see below)  
IC4 = 7805  
LD1;LD2;LD3 = HD11070 (orange)

### Miscellaneous:

K1;K2;K3 = PCB mount line socket.  
K4 = 2-way PCB terminal block, raster 5mm.  
S1;S2 = Digitast presskey w. 12mm cap.  
Printed circuit board plus programmed PIC (IC3); set order code 940065 (page 70). The PIC is also available separately as order code 946643-1 (page 70).

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### COMPONENTS

Components for projects appearing in *Elektor Electronics* are usually available from appropriate advertisers in this magazine. If difficulties in the supply of components are envisaged, a source will normally be advised in the article. It should be noted that the source(s) given is (are) not exclusive — other suppliers may also be able to help.

### BOOKS

For book availability, see advertisement on page 81.

### SHELF BOX

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### FRONT PANEL FOILS

PROJECT	No.	Price (£)	Price (\$US\$)
4MB printer buffer card	920009-F	8.25	16.50
LC meter	920012-F	11.45	22.90
Guitar tuner	920033-F	8.80	17.60
NICAM decoder	920035-F	8.25	16.50
12VDC to 240VAC inverter	920038-F	16.15	32.30
Audio DAC	920063-F	10.00	20.00
Dig. audio/visual system	920022-F1	10.00	20.00
	920022-F2	19.40	38.80
	920022-F3	28.80	57.60
1.2 GHz multifunction frequency meter	920095-F	13.80	27.60
U2400B NiCd battery charger	920098-F	8.75	17.50
Workbench PSU	930033-F	17.00	34.00
Inexpensive phase meter	930046-F	17.25	34.50
Mini preamplifier	930106-F	Not available	
AF rms voltmeter	930108-F	17.25	34.50

PROJECT	No.	Price (£)	Price (\$US\$)
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### EPROMS / PALS / MICROCONTROLLERS

EMON51 (8051 assembler course) (1 x 27256+disk 1661)	6061	20.00	40.00
EMON51 (8051 assembler course) (1 x 27256+disk 1681)	6091	20.00	40.00
FM tuner (1 x 27C256)	6101	15.30	30.60
Multi-purpose Z80 card: GAL set (2 x GAL 16V8)	6111	11.15	22.30
Multi-purpose Z80 card: BIOS (1 x EPROM 27128)	6121	15.30	30.60
1.2 GHz multifunction frequency meter (1 x 27C256)	6141	11.45	22.90
Digital audio/visual system (1 x 27C256)	6171	10.30	20.60
TV test pattern generator (1 x 27256)	6151	13.00	26.00
DIVAV system: Package: 1 x 27512; 2 x GAL; 1 x floppy disk (MSDOS)	6181	30.50	61.00
PAL test pattern generator (1 x GAL 20V8-25)	6211	9.40	18.60
80C535 assembler course (1 x EMON52 EPROM and 1 x disk 1811)	6221	17.05	34.10
Watt-hour meter (1 x 27256)	6241	10.00	20.00
Four fold DAC (1 x GAL)	6251	10.75	21.50
Multipurpose display decoder (1 x 2764)	6261	11.50	23.00
Telephone-controlled switch (1 x 2764)	6271	14.50	29.00
Relative humidity meter (1 x 2764)	6301	14.50	29.00
535 card w. EPROM emulator (1 x PAL; 1 x GAL)	6311	26.00	52.00
Copybit eliminator (1 x GAL 16V8 and 1 x MACH110)	6321	42.25	84.50
RDS decoder (1 x 27C64)	6331	14.50	29.00
I2C tester (1 x GAL 6001)	6341	30.75	61.50
Mains signalling system (1 x 27C64)	6371	13.25	26.50
8751 programmer (1 x 8751)	7061	46.40	92.80
Microcontroller NiCd charger (1 x ST62E15)	7071	10.00	20.00
Maxi micro clock (clock)	7081	11.50	23.00
Maxi micro clock (darkroom timer)	7091	11.50	23.00
Maxi micro clock (cooking timer)	7101	11.50	23.00
Mini micro clock (clock)	7111	11.50	23.00
Mini micro clock (darkroom timer)	7121	11.50	23.00
Mini micro clock (cooking timer)	7131	11.50	23.00
VHF/UHF TV tuner (1 x 87C51)	7141	25.75	51.50
Microntroller-driven UART (1 x ST62T10)	7151	17.25	34.50
PIC programmer (1 x PIC17C42 and 1 x disk)	7161	52.75	105.50
<b>TV line monitor</b> (1 x PIC16C54)	946443-1	20.25	40.50
MIDI swell pedal (1 x 27C64)	946635	13.75	27.50

PROJECT	No.	Price (£)	Price (\$US\$)
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Mains signalling system	1911	9.75	19.50
SIM — an 8051 simulator	1931	34.25	68.50
80C535 SBC extension	1941	9.75	19.50
80C535 SBC I2C display	946197-1	9.75	19.50
Small loop antennas	1951	10.75	21.50
<b>PIC programming course</b>	946196-1	9.75	19.50
RC5 transmitter w. 80C535	946199-1	9.75	19.90

PRINTED CIRCUIT BOARDS
Printed circuit boards whose number is followed by a + sign are only available in combination with the associated software item, and can not be supplied separately. The indicated price includes the software.

### APRIL 1994

Mains signalling system - 1 (receiver)	940021-1	10.25	20.50
68HC11 processor board	930123	7.75	15.50
RS232 speedometer	930119	Not available	
Stroboscope light	940022	Not available	
Headphones amplifier	940016	18.75	37.50
Halogen light dimmer	940034	Not available	
RS232 interface for universal bus	924048	Not available	

### MAY 1994

Differential probe for oscilloscopes	940018	7.75	15.50
Mains signalling system - 2 (transmitter) (incl. disk 1911 and EPROM 6371)	940021-2+	33.25	66.50
Morse decoder	contact Velleman distributor		
General-purpose sensor monitor	916107	Not available	
TV sound to light unit	936038	Not available	

### JUNE 1994

80C535 SBC extension	940025+	19.75	39.50
I2C bus booster	940057	7.25	14.50
RS485 interface	940035	6.25	12.50
Fuel consumption monitor	940045	6.00	12.00
Intelligent EPROM eraser	940058-1	9.00	18.00

### JULY/AUGUST 1994

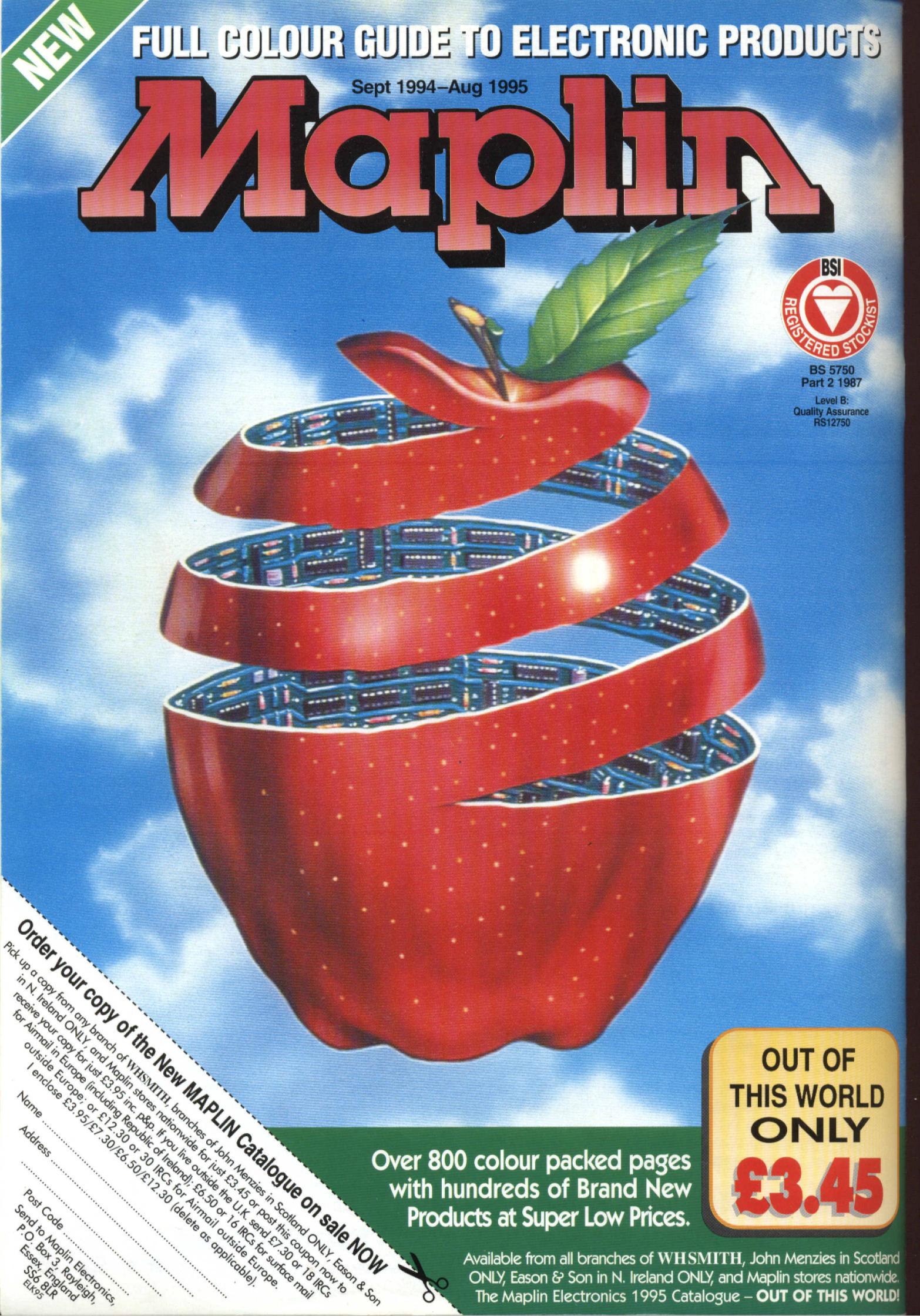
Gen. purpose IR volume control	930099	9.00	18.00
IR controlled switch	936066	9.75	19.50
MIDI swell pedal, incl. EPROM 946635	940019-C+	26.75	53.50
Charge meter	940033	5.75	11.50
Water softener	944011-1	6.00	12.00
Joystick-to-mouse adaptor	944040-1	7.00	14.00
Discrete preamplifier	944063-1	8.50	17.00
Centronics I/O interface	944067-1	8.75	17.50
80C451 controller board	944069-1	15.00	30.00
Robust AF power amp	944075-1	9.75	19.50
PC over-temperature alarm	944076-1	4.25	8.50
1.4 MByte SIMM adaptor	944094-1	15.50	31.00
Optical doorbell	944080-1	6.25	12.50
PIC experimenting board	944105-1	17.75	35.50
RC5 transmitter w. 80C535 incl. disk 946199	944106-C+	13.00	26.00
Car battery monitor	936042	Not available	
Resettable fuse for caravans	940061	Not available	

### SEPTEMBER 1994

Switchable a.c. supply	934004	6.50	13.00
Anemometer & flow meter	940017	6.25	12.50
Compact frequency meter	940051-1	9.00	18.00
Revolution counter	940045-1	6.00	12.00
	940068-1	5.50	11.00
Battery monitor	940003	Not available	

### OCTOBER 1994

Motive-battery charger	940083	7.25	14.50
Integrated AF amplifier	936062-1	9.50	19.00
	936062-2	28.25	56.50
Tester for IR remote control	940084-1	6.50	13.00
Computer PSU monitor	940087	Not available	
Stable dc-dc converter	940097	Not available	
In-car audio amplifier (1)	940078-1	14.00	28.00
TV line monitor (incl. PIC)	940065+	26.25	52.50



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